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Validation of no-decompression dive limits and procedures for CUMA operations – final report

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Defence R&D Canada – Toronto
Technical Report
DRDC Toronto TR 2003-029
June 2003

Canada

104-05566/

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Abstract

The Canadian Underwater Mine-countermeasures Apparatus (CUMA) uses decompression tables developed and tested at DRDC Toronto (formerly the Defence and Civil Institute of Environmental Medicine (DCIEM)) to support diving to 81 metres of seawater (msw) on a breathing mixture of helium and oxygen. The no-decompression limits in these tables were not intended to be true no-decompression limits but were convenient times intended primarily for training and dive abort purposes for depths from 15 to 45 msw. The need for more realistic no-decompression limits and the extension of no-decompression diving to deeper depths included enhancing operational flexibility when undertaking short duration inspection dives, for dive abort emergency situations, and improving training and work-up programmes. A study of the DCIEM™ decompression algorithm supported extending the no-decompression limits for CUMA to 69 msw and reducing the decompression requirements for deeper short duration dives (72 and 75 msw).

Validation experiments were conducted between November 1999 and February 2002. Fifty-seven volunteer divers from the Canadian Forces (DRDC Toronto, Fleet Diving Unit (Atlantic), Fleet Diving Unit (Pacific)), Royal Navy, Royal Australian Navy, Royal New Zealand Navy, US Navy Experimental Diving Unit, and the Polish Navy participated in these trials. Dive subjects breathed from CUMA in 6 to 8°C water in a hyperbaric chamber. Inhale breathing gas was analysed continuously for oxygen and carbon dioxide. Doppler ultrasound was used for venous gas bubble detection for a minimum of 2 hours (h) after the first and second dives. Dives were repeated after 6 h to ensure that there would be no decompression penalties associated with the second dives (Nishi *et. al.*, DCIEM TR 000-063).

A total of 128 dives (505 man-dives, with 435 being used for validation purposes) were carried out. Doppler monitoring showed that the extended bottom time limits were safe and that the differences in observed bubble scores between dives separated by 6 h were not significantly different. One case of decompression illness was observed. As a result, recommendations were made to include new no-decompression limits for diving CUMA to a maximum depth of 69 msw and reduction of stop times at 72 and 75 msw.

Résumé

L'appareil canadien de déminage sous-marin (ACDSM) fait appel à des tables de décompression élaborées et éprouvées par RDDC Toronto (anciennement l'Institut militaire et civil de médecine environnementale [IMCDE]) pour appuyer les plongées effectuées à une profondeur de 81 mètres d'eau de mer (msw pour meters of sea water) avec un mélange respiratoire constitué d'hélium et d'oxygène. Les limites de non-décompression de ces tables ne constituent pas des limites absolues de non-décompression, mais plutôt des limites convenant aux activités de formation et à l'interruption d'urgence des plongées effectuées entre 15 et 45 msw de profondeur. Pour élaborer des limites de non-décompression plus réalistes et étendre la portée de celles-ci aux plongées à grande profondeur, il a fallu améliorer la souplesse opérationnelle lors des plongées d'inspection de courte durée, surtout pour l'interruption d'urgence des plongées, et améliorer également les programmes de formation et d'entraînement. L'étude de l'algorithme de décompression de l'IMED™ proposait d'étendre les limites de non-décompression de l'ACDSM aux plongées effectuées à 69 mètres de profondeur et de réduire les exigences en matière de décompression pour les plongées de courte durée effectuées à des profondeurs variant entre 72 et 75 msw.

Des expériences de validation ont été réalisées entre novembre 1999 et février 2002. Cinquante-sept plongeurs volontaires des Forces canadiennes (RDDC Toronto, unité de plongée de la flotte atlantique, unité de plongée de la flotte pacifique), de la Marine royale, de la marine australienne, de la marine néo-zélandaise, de l'unité de plongée expérimentale de la U.S. Navy et de la marine polonaise) ont pris part à ces essais. Les sujets, qui prenaient place dans un caisson hyperbare contenant de l'eau dont la température oscillait entre 6 et 8 °C, respiraient au moyen de l'ACDSM. Le mélange respiratoire était sous constante surveillance afin d'en analyser la teneur en oxygène et en gaz carbonique. Un appareil Doppler a été utilisé pour détecter la présence de bulles d'azote dans le sang pendant les deux heures qui ont suivi la fin de la première et de la deuxième plongée. Les sujets ont plongé à nouveau six heures plus tard afin de s'assurer qu'il n'était pas nécessaire d'accroître le temps de décompression lors de la deuxième plongée (Nishi *et. al.*, IMED TR 000-063).

Au total, 128 plongées ont été effectuées (505 plongées-personne, dont 435 ont servi aux fins de validation). La surveillance au moyen de l'appareil Doppler a permis de constater que les temps de plongée limites étaient sécuritaires et que la quantité de bulles d'azote formées dans l'organisme lors des deux plongées effectuées à six heures d'intervalle était sensiblement la même. Un plongeur a souffert du mal de décompression. Suite à cet incident, il a été recommandé d'appliquer de nouvelles limites de non-décompression pour les plongées effectuée avec l'ACDSM à une profondeur de 69 msw et de réduire les temps d'arrêt à 72 et 75 msw de profondeur.

Executive summary

Introduction. The Canadian Underwater Mine-countermeasures Apparatus (CUMA), developed in the late 1980's to support diving to 81 msw on a breathing mixture of helium and oxygen, uses decompression tables developed and tested at DRDC Toronto (formerly the Defence and Civil Institute of Environmental Medicine (DCIEM)) (Nishi and Warlow, DCIEM Report No. 97-R-68). The no-decompression limits in these tables were limited to depths from 15 to 45 msw and were not intended to be true no-decompression limits but were convenient times intended primarily for training and dive abort purposes. The need for more realistic no-decompression limits and the extension of no-decompression diving to deeper depths included enhancing the operational flexibility available when undertaking short duration inspection dives, for dive abort emergency situations, and improving training and work-up programmes.

Methods. A study of the DCIEM™ decompression algorithm supported extending the no-decompression limits for CUMA to 69 msw and reducing the decompression requirements for deeper short duration dives (72 and 75 msw). Testing was conducted between November 1999 and February 2002 following the successful completion of trials to reduce the surface interval between successive CUMA dives to 6 hours (h) without any decompression penalties (Nishi *et. al.*, DCIEM TR 000-063) and concurrently with repetitive dive trials for 3 h surface intervals (Nishi *et. al.*, DRDC TR 2003-028). Dives were repeated after 6 h to ensure that there would not be any decompression penalties associated with the second dives. Fifty-seven volunteer divers from the Canadian Forces (DRDC Toronto, Fleet Diving Unit (Atlantic), Fleet Diving Unit (Pacific)), Royal Navy, Royal Australian Navy, Royal New Zealand Navy, US Navy Experimental Diving Unit, and the Polish Navy participated in these dives.

Results. A total of 128 dives (505 man-dives, with 435 being used for validation purposes) were carried out. Doppler monitoring of the subjects for decompression-generated bubbles showed that the extended bottom time limits were safe and that the differences in observed bubble scores between dives separated by 6 h were not significantly different. One case of decompression illness was observed.

Significance. Operationally, the ability of divers to make short inspection dives of mine-like objects at deeper MCM depths is improved, while concurrently reducing the exposure of the diver and the dive safety boat to the mine threat, and more rapidly returning the MCM vessel to its primary mine hunting task. Longer no-decompression limits mean that in a wider range of emergencies the diver will have time to make a controlled ascent to the surface without the constraint of stops or omitted decompression. During career and continuation training, divers can complete the required work-up profiles in a shorter time.

Nishi RY, Woodward DJ, Eaton DJ. 2003. Validation of no-decompression limits and procedures for CUMA operations – final report. DRDC Toronto TR 2003-029. DRDC Toronto.

Sommaire

Introduction. L'Appareil canadien de déminage sous-marin (ACDSM), conçu à la fin des années 1980 pour appuyer les plongées effectuées à une profondeur de 81 mètres d'eau de mer avec un mélange respiratoire composé d'hélium et d'oxygène, fait appel à des tables de décompression élaborées et éprouvées par RDDC Toronto (anciennement l'Institut militaire et civil de médecine environnementale - IMCME) (Nishi et Warlow, Rapport de l'IMED n° 97-R-68). Les limites de non-décompression qui figurent dans ces tables ne visent que les plongées effectuées à des profondeurs variant entre 15 et 45 msw et ne constituent pas des limites absolues de non-décompression. Elles servent plutôt de limites convenant aux formations et aux fins d'interruption d'urgence des plongées. Pour élaborer des limites de non-décompression plus réalistes et étendre la portée de celles-ci aux plongées à grande profondeur, il a fallu améliorer la souplesse opérationnelle lors des plongées d'inspection de courte durée, surtout pour l'interruption d'urgence des plongées, et améliorer également les programmes de formation et d'entraînement.

Méthode. L'étude de l'algorithme de décompression de l'IMED™ proposait d'étendre la portée des limites de non-décompression aux plongées effectuées à 69 msw de profondeur avec l'ACDSM et de réduire les exigences relatives à la décompression pour les plongées de courte durée à grande profondeur (72 et 75 msw). Des essais ont été réalisés entre novembre 1999 et février 2002 suite aux essais réussis visant à réduire à six heures l'intervalle à la surface entre deux plongées effectuées avec l'ACDSM, sans que le temps de décompression de la deuxième plongée ne soit accru (Nishi *et. al.*, IMED TR 000-063). D'autres essais ont ensuite été menés afin de réduire l'intervalle à la surface à 3 heures (Nishi *et. al.*, RDDC TR 2003-028). Des plongées ont été effectuées six heures après la fin de la première afin de s'assurer qu'il n'était pas nécessaire d'augmenter le temps de décompression pendant la deuxième plongée. En tout, cinquante-sept plongeurs volontaires des Forces canadiennes (RDDC Toronto, unité de plongée de la flotte atlantique, unité de plongée de la flotte pacifique), de la Marine royale, de la marine australienne, de la marine néo-zélandaise, de l'unité de plongée expérimentale de la U.S. Navy et de la marine polonaise ont pris part à cet exercice.

Résultats. Au total, 128 plongées ont été réalisées (505 plongées-personne, dont 435 ont été effectuées aux fins de validation). La surveillance des sujet au moyen de l'appareil Doppler pour détecter les bulles d'azote qui se forment dans l'organisme a permis de constater que les temps de plongée étaient sécuritaires et que la différence au niveau des bulles d'azotes dans le sang pendant la période de 6 heures entre les deux plongées n'était pas significative. Un seul plongeur a souffert du mal de décompression.

Portée. Sur le plan opérationnel, la capacité des plongeurs à effectuer des activités d'inspection de courte durée, à des profondeurs plus prononcées, se trouve à être accrue, tandis que l'exposition du plongeur et de l'embarcation de sauvetage aux mines se trouve à être réduite, ce qui permet à l'embarcation de déminage de se concentrer sur sa tâche primaire qui est la chasse aux mines. L'adoption de limites de non-décompression

accrues signifie que dans de nombreuses situations d'urgence, le plongeur sera en mesure de prendre le temps nécessaire pour effectuer une remontée contrôlée, sans être obligé de s'arrêter à certains paliers ou de négliger le processus de décompression. Ainsi, tout au long de leur carrière, et pendant la formation continue, les plongeurs sont en mesure de compléter leur profil d'entraînement en un temps réduit.

Nishi RY, Woodward DJ, Eaton DJ. 2002. Validation of no-decompression limits and procedures for CUMA operations – final report. DRDC Toronto TR 2003-029. DRDC Toronto.

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Acknowledgements

The authors would like to acknowledge the valuable managerial support and operational perspective provided by Lt Cdr Mark Kessler, RN (Retd), who as Project Officer, provided the impetus to initiate this research and managed the first two experimental dive series; by Mr. David Eastman, Sgt. Dimitrih Lafleur, and Mrs. Macella Maxwell for Doppler monitoring and ensuring that all the required subject data, Doppler results and dive data, were entered into the DRDC Toronto dive and decompression database; by Mr. Robert MacLean for the acquisition and monitoring of dive and life support data; by LCdr. Aaron Khan, Dr. David Sawatzky and LCdr. Debbie Pestell for medical support; by PO1 Bruce Irwin and PO1 Jocelyn Boisvert (Retd) for subject and experimental logistics; and by all the other members of the Experimental Diving Unit Diving R&D Group and Diving Operations Group. In addition, support was provided by the Central Medical Board backup medical coverage, and by various other sections within DRDC Toronto. The significant commitment by the contributing National Navies of the United States, United Kingdom, Australia, New Zealand and Canada warrants special note, for without their tremendous support in the provision of numerous volunteer experimental dive subjects, this project would not have been completed in such a timely manner. The dedication, commitment and long hours put in by all the participants were vital ingredients to the success of this project.

1. Introduction

The conduct of Mine Countermeasures (MCM) diving operations has historically been driven by the number of divers in the deployed team, the maximum operating depth, and the type of diving equipment available. Dive teams tended to be supported with enough personnel to allow continuous diving operations during a mission. In recent years, the reduction in the availability of trained MCM divers and the diversity of skills required by those divers has led to specialised small teams being dedicated for the MCM role. At the same time, the depth that those teams are expected to work at has increased from 55 to 81 metres of seawater (msw). The Canadian Underwater Mine Countermeasures Apparatus (CUMA) was developed in the late 1980's to meet this commitment [1]. Decompression tables (CF Table 10 for no-decompression diving, CF Table 11 for in-water oxygen decompression; and CF Table 12 for surface decompression with oxygen) [2] were subsequently developed and tested at the DRDC Toronto[1] to support diving to 81 msw on a helium-oxygen breathing mixture [3]. In addition, trials were conducted to show that a second CUMA dive could be conducted after a reduced surface interval of 6 hours (h) without incurring any decompression penalties [4] and repetitive dive tables were developed and tested for surface intervals from 3 to 6 h [5].

The original no-decompression limits in CF Table 10 were limited to depths from 15 to 45 msw. The bottom times were not intended to be true no-decompression limits but were convenient times intended primarily for training and dive abort purposes. The need for more realistic no-decompression limits and the extension of no-decompression diving to deeper depths included enhancing the operational flexibility when undertaking short duration inspection dives, for dive emergency situations, and improving training and work-up programmes. For example, the US Navy decompression tables for the Mark 16 closed circuit rebreather [6] give no-decompression dives to 81 msw for 5 min. A study of the DCIEM™ decompression algorithm supported extending the no-decompression limits for CUMA to 69 msw and for deeper, short duration dives (72 and 75 msw), a reduction of the previous in-water decompression stops.

This report covers the development and validation of the extended no-decompression limits and the deep short dives with limited in-water decompression. Testing was conducted between November 1999 and February 2002 following the successful completion of trials to reduce the surface interval between successive CUMA dives without incurring any decompression penalties to 6 h [4] and concurrently with repetitive dive trials for surface intervals from 3 to 6 h [5]. Dives were repeated after 6 h to ensure that there would be no decompression penalties associated with the second dives.

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[1] DRDC Toronto was formerly known as DCIEM or the Defence and Civil Institute of Environmental Medicine. The DCIEM acronym and name are now registered trademarks. Although these experiments were conducted under the DCIEM name, the DRDC Toronto name will be used in this document for consistency and clarity.

Dive subjects were from the Canadian Forces (CF) (DRDC Toronto, Fleet Diving Unit (Atlantic) (FDU(A)), Fleet Diving Unit (Pacific) (FDU(P))), Royal Navy (RN), Royal Australian Navy (RAN), Royal New Zealand Navy (RNZN), US Navy Experimental Diving Unit (USNEDU), and the Polish Navy.

2. Background

The CUMA diving equipment utilises a supply of helium (He) and oxygen (O_2) to provide the diver with a nominal constant partial pressure of O_2 (PO_2) of 1.6 atmospheres absolute (ATA) at all depths. This is achieved by the addition of a variable flow of diluent (He) gas to a constant mass flow of O_2 at 3.6 litres·min-1at 0°C at 1 ATA (slm). At the surface, only pure O_2 is supplied to the breathing loop; then once the depth increases past 6 msw, the diluent gas flow rate increases linearly in proportion to depth. The combined flow of O_2 and He produces a heliox (HeO_2) gas mixture entering the breathing loop with a PO_2 of 1.6 ATA, with an allowable range of 1.5 ATA to 1.7 ATA at depths of 10 msw to 81 msw. The PO_2 in the breathing loop depends on the diver's work rate but should not exceed 1.62 ATA when the diver is at rest (assuming a metabolic O_2 consumption rate ($\dot{V}O_2$) of 0.25 slm), nor drop below a minimum of 0.29 ATA if the diver is working strenuously (assuming $\dot{V}O_2$ of 3.0 slm) for an extended period [1]. For calculating decompression tables, a time-weighted average (TWA) PO_2 of 1.0 ATA has been assumed based on empirical results [3].

The use of 1.0 ATA PO_2 leads to relatively conservative decompression tables for short duration dives. For such dives, the time-weighted average PO_2 can be much higher and some decompression stops may become unnecessary, leading to an extension of the no-decompression bottom times and depths. There are a number of benefits to this for both operational and diver safety considerations, as follows.

Previously, in the event of equipment malfunction or diver distress during short duration dives, a diver's ascent may have been delayed by the existing decompression obligation, or, if intent on surfacing under these circumstances, the diver may have been committed to an omitted decompression treatment. With improved no-decompression limits, the diver may now make a controlled ascent from deeper no-decompression profiles to the surface and subsequently breathe atmospheric air without these unnecessary constraints.

Operationally, the ability of divers to make short inspection dives of mine like objects at deeper MCM depths is improved. Previously required decompression stops might have exposed the diver or the accompanying dive safety boat in the immediate explosive vicinity of the mine threat, or, if the object was a non-mine, would have delayed the MCM vessel from continuing with its primary mine hunting task.

In terms of diver utility, dive teams are not so likely to be "dived out" by unnecessary decompression limits, i.e., being unavailable for further dives in a specific time period due to "combined dive" rules. This could be further enhanced by the ability to complete a second dive after only 6 h rather than the previously held belief that dives needed to be separated by 18 h [4]. Therefore a dive team is more readily available for continued tasking. In addition, these improved limits increase dive team flexibility for rapid workup to the required depth dive profiles during training.

In terms of safety, improved no decompression limits also allow the dive supervisor to deploy the standby diver in any potential emergency situation. The standby diver can make a short duration dive and not necessarily be committed to decompression, whatever the needs of the casualty diver. This greatly simplifies the supervisor's priorities during an incident. If the standby diver has to be deployed for a brief period, he may, depending on his previous dive profile, continue to be used as a standby diver, at the discretion of the Supervisor. Previously this was not an option.

2.1 Development of no-decompression limits

The original no-decompression times from CF Table 10 are shown in Table 1 along with the US NEDU no-decompression limits for 0.7 ATA PO_2 in helium based on the HVAL-21 decompression algorithm [7], the USNEDU no-decompression limits for 1.3 ATA PO2 based on USN probabilistic decompression model [6], and the no-decompression limits found in DERA Table 90 for 1.3 ATA PO_2 in helium [8]. It should be noted that the CUMA no-decompression dive trials were not intended to establish no-decompression limits but to provide sufficient bottom time for training or operational purposes while keeping dives in a low decompression stress range (i.e., with minimal bubble scores), and also, if necessary, to abort dives at the deeper depths without running into an omitted decompression situation. Thus, they were much more conservative than the US Navy limits. The reduction in the bottom time at 12 msw was made for practical reasons since the underwater endurance of the CUMA set was rated at 120 min. (With improvements in the set, the endurance is now rated at 180 min.)

Table 1. *CF CUMA Table 10 and other No-Decompression Times for Oxygen in Helium*

DEPTH (msw)	NO-DECOMPRESSION TIMES (min)				DEPTH (msw)	NO-DECOMPRESSION TIMES (min)			
	CF TABLE 10	USNEDU (0.7 ATA)	USNEDU (1.3 ATA)	DERA[1] Table 90 (1.3 ATA)		CF TABLE 10	USNEDU (0.7 ATA)	USNEDU (1.3 ATA)	DERA Table 90 (1.3 ATA)
12	120	390	720		48	-	8	12	5
15	70	214	325	310	51	-	8	11	6
18	35	137	134	127	54	-	7	10	5
21	25	85	86	70	57	-	6	9	5
24	15	54	63	42	60	-	6	8	5
27	11	38	44	28	63	-	5	5	5
30	10	30	31	20	66	-	5	5	5
33	10	23	24	15	69	-	5	5	5
36	9	18	20	11	72	-	5	5	-
39	8	14	17	10	75	-	4	5	-
42	7	11	15	8	78	-	4	5	-
45	6	10	13	6	81	-	-	-	-

1. Descent rate of 30 msw/min and ascent rate of 15 msw/min

During Series 1 to 4 of the CUMA decompression tables validation trials [3], a total of 124 man-dives were carried out on CF Table 10 bottom times at 15, 18, 24, 27, 33, 42, and 45 msw. The Doppler results showed that these bottom times gave very low decompression stress with only a few Doppler-detectable bubbles in the precordial region. Bubbles were more commonly observed in the subclavian veins; of 24 man-dives that resulted in detectable bubbles, 21 had bubbles in the subclavian veins only. Only two subjects had Grade III bubbles, one at 24 msw/15 min (precordial) and the other at 27 msw/11 min (subclavian). Eighteen of the balance only had bubbles at the Grade I level. These results showed that the CF Table 10 bottom times were extremely conservative. The limits were calculated with a Time-Weighted Average (TWA) PO_2 of 1.0 ATA. However, measured PO_2 levels showed that the TWA PO_2 for the no-decompression dives tested was generally higher, varying from 1.1 to 1.3 ATA [3].

In planning for extended no-decompression times for depths greater than 45 msw, it was assumed that the US Navy HVAL-21 limits [7], as a minimum, should be attainable. However, the maximum depth was limited to 69 msw/5 min, since for deeper depths, the actual time at bottom based on a correct descent rate of 18 msw/min leaves very little time to for useful work. Another consideration was that the margin for error becomes increasingly narrow at the deeper depths and there was the possibility of a high risk of serious decompression illness (DCI) occurring if problems were encountered during the dives. Thus, for dives at 72 and 75 msw, a short in-water decompression stop was considered to be necessary.

The decompression model for CUMA diving, when used to calculate no-decompression dives, gives extremely conservative bottom time limits. Although the CUMA schedules were calculated with a TWA PO_2 of 1.0 ATA (for decompression-required dives), PO_2 data from CUMA dives undertaken in the CUMA table validation trials [3], the reduced surface interval [4] and repetitive dive trials [5] showed that the mean TWA PO_2 could be around 1.3 ATA for the deeper depths. Thus, the model was modified to fit no-decompression limits of 45 msw/10 min, 54 msw/7 min, 60 msw/5 min and 69 msw/5 min for a TWA PO_2 of approximately 1.3 ATA. Furthermore, the model parameter changes were designed so that dives requiring decompression stops (based on a PO_2 of 1.0 ATA) would be affected only minimally. Otherwise, it would have necessitated retesting of dives done previously. For depths less than 42 msw, previous PO_2 data showed that the mean TWA PO_2 could be as low as 1.1 ATA. For these depths, no-decompression limits were calculated for PO_2 values from 1.0 to 1.3 ATA.

The depth and time columns in Table 2 give the proposed no-decompression limits. For depths less than 42 msw, the bottom times are considerably more than those in CF Table 10 but not as much as those for the US Navy 0.7 ATA PO_2 no-decompression limits (Table 1). The other columns in Table 2 show the mean TWA PO_2 expected from leaving surface to the end of the proposed bottom times for 30 to 75 msw. These were obtained from PO_2 data from CUMA dives carried out during the table validation trials and the reduced surface interval and repetitive dive trials [3-5]. For 15 msw, PO_2 values were obtained from the original no-decompression dives carried out during the validation trials [3]. For 18 to 27 msw, no dives were available with bottom times in excess of the proposed no-decompression limits and a TWA PO_2 could not be inferred.

Table 2. *Proposed No-decompression Limits and Expected Time-Weighted Average PO_2 (to end of Bottom Time)*

Depth (msw)	Time (min)	Wet Divers[1]				Standby Divers[1]			
		No. divers	Mean PO_2 ± SD	Max	Min	No. divers	Mean PO_2 ± SD	Max	Min
12	120								
15	75	14[2]	1.26 ± 0.05	1.33	1.16	5[2]	1.49 ± 0.02	1.51	1.46
18	55								
21	40								
24	30								
27	25								
30	20	24	1.12 ± 0.06	1.22	1.00	15	1.28 ± 0.05	1.37	1.21
33	17	19	1.15 ± 0.07	1.27	1.03	11	1.28 ± 0.06	1.35	1.12
36	14	4	1.20 ± 0.20	1.37	0.94	2	1.36 ± 0.04	1.38	1.33
39	12	43	1.13 ± 0.08	1.33	0.98	22	1.26 ± 0.08	1.4	1.13
42	11	14	1.13 ± 0.07	1.29	1.03	8	1.25 ± 0.04	1.29	1.20
45	10	93	1.17 ± 0.08	1.43	1.01	50	1.29 ± 0.11	1.58	1.14
48	9	24	1.23 ± 0.08	1.42	1.08	12	1.31 ± 0.07	1.48	1.23
51	8	48	1.25 ± 0.07	1.39	1.01	26	1.31 ± 0.09	1.45	1.09
54	7	32	1.30 ± 0.08	1.43	1.09	15	1.31 ± 0.13	1.51	1.08
57	6	23	1.31 ± 0.13	1.60	1.03	12	1.36 ± 0.08	1.52	1.23
60	6	140	1.35 ± 0.11	1.68	1.10	70	1.36 ± 0.11	1.66	1.11
63	5	24	1.41 ± 0.11	1.61	1.19	12	1.35 ± 0.10	1.53	1.14
66	5	20	1.34 ± 0.13	1.64	1.14	10	1.37 ± 0.15	1.61	1.15
69	5	150	1.43 ± 0.13	1.78	1.15	74	1.42 ± 0.15	1.78	1.15
72	5[3]	12	1.41 ± 0.11	1.68	1.28	6	1.43 ± 0.08	1.55	1.31
72	6[3]	12	1.44 ± 0.11	1.71	1.31	6	1.45 ± 0.07	1.56	1.36
75	6[3]	43	1.45 ± 0.14	1.75	1.18	22	1.40 ± 0.12	1.71	1.18

Note 1: Standby divers are partially wet and resting, while wet divers are fully immersed. For depths greater than 48 msw, wet divers are also resting since there is insufficient time to carry out any work cycles (see para. 3.2).

2. Data for 15 msw taken for 15 msw/70 min no-decompression dives [3].

3. Dives with short in-water decompression stops, not no-decompression.

3. Methods

3.1 Dive subjects

Qualified volunteer divers from the CF, USN, RN, RAN and the RNZN served as subjects during the dive trials and were made available by the participating navies for up to a month at a time. In addition, two diving officers from the Polish Navy participated in one series, with one as a dive subject. DRDC Toronto divers participated as both dive subjects and team leaders. Team leaders were counted as dive subjects for dives in which they used CUMA. All visiting divers received three days training and indoctrination in the experimental procedures and the use of CUMA prior to each series of experimental dives. Pre-series medical assessments that included age, height, weight and skin fold calliper measurements were also carried out. These are shown in Table A1, Annex A. Daily questionnaires were completed by the divers prior to each dive covering pre-dive exercise, sleep pattern, alcohol in-take, smoking habits, food and fluid in-take and any medication taken that might have a possible influence on the dive.

3.2 Procedures

The experimental dive program was approved by the DRDC Toronto Human Research Ethics Committee [9-12]. All dives were carried out in the DRDC Toronto Diving Research Facility (DRF) in accordance with EDU Experimental OPERATIONAL ORDERS for each series of experiments, starting with Series 7 [13] and culminating in Series 12 [14]. The water temperature for all dives was between 6-8°C.

Divers were assigned to one of two 5 to 6-man dive teams, with each team diving on alternate days. This was to ensure that there would be at least one full day of rest between dives for any given diver. Where not enough subjects were available to make a full dive team or a subject was unable to dive on a scheduled dive day, the team was augmented by DRDC Toronto divers or, failing that, some subjects were required to dive on consecutive days.

Each dive was planned for four divers: two wet divers (designated Red and Yellow), one standby diver (partially wet, resting) breathing from the CUMA, and one team leader (dry, lightly working). The three CUMA divers repeated the same dive after 6 h. During the initial series, the team leader breathed a 75% He/25% O_2 mixture from the DRF Built-in Breathing System (BIBS); he was replaced by a new team leader for the second dive. However, with the arrival of the CUMA V2 set, a much lighter set than the production sets used by the wet and standby divers for these trials, team leaders switched to the CUMA V2 and participated in both dives of the day. As a result, they were counted as dive subjects. Team leaders were DRDC Toronto divers for the majority of the dives.

Table 3 shows the no-decompression dives that were intended for testing. In addition to these dives, several dives to 72 and 75 msw with a short in-water stop before surfacing

were planned. In these dives the team leader again breathed a 75% He/25% O_2 or an 80%He/20%O_2 mixture from the DRF BIBS, changing to air at the 12 msw stop and O_2 at the 9 msw stop; he then undertook the second dive after the 6 h break. These dives were not included in the data analysis since they were not CUMA dives.

***Table 3**. Dive Profiles Tested*

Primary No-decompression Dives					
Depth (msw)	Bottom Time (min)	In-Water Stops			Total Dec. Time (min)
		Heliox		O_2	
		15	12	9	
45	10	-	-	-	3
54	7	-	-	-	3
60	5*	-	-	-	4
60	6	-	-	-	4
69	5	-	-	-	4
Note: * Changed to 60 msw/6 min after 9 dive pairs completed, see Results for details					
Deep, Short Decompression Dives					
72	5	-	-	5	10
72	6	-	4	6	11
75	6	-	4	10	15
Note: Initial profiles planned. See Results for final profiles tested.					

Secondary No-decompression Dives					
Depth (msw)	Bottom Time (min)	In-Water Stops			Total Dec. Time (min)
		Heliox		O_2	
		15	12	9	
18	55	-	-	-	1
30	20	-	-	-	2
36	14	-	-	-	2
42	11	-	-	-	3
48	9	-	-	-	3
51	8	-	-	-	3
63	6**	-	-	-	4
63	5	-	-	-	4
Note: ** Changed to 63 msw/5 min after 1st dive					

Prior to each dive, each CUMA set was bench tested and calibrated. The carbon dioxide (CO_2) scrubber was charged using soda lime (Molecular Products Limited Sofnolime 8-12 Mesh) meeting CF specifications [15]. On completion of the calibrations and bench tests, the CUMA sets were assembled, leak-tested and the integrity of the apparatus confirmed by a qualified EDU technician. The CUMA sets were then transferred to the DRF and connected to the data acquisition tether.

The subjects were briefed prior to each dive. The wet divers and standby diver were then dressed in well-fitting neoprene dry suits, thermal underwear, gloves and hood and entered the dive chamber. They donned their CUMA and each gas supply was switched on at not more than 5 min before descent, so as to keep O_2 prebreathing to a minimum. The dive subjects entered the water and their equipment was checked for leaks. If any leaks or malfunctions were encountered that could not be resolved well within 5 min, all subjects stopped breathing from the CUMA sets and went on to chamber air until the problems could be corrected. On completion of the leak test, the divers moved to their designated positions in preparation for descent. The objective was to ensure that no more than 5 min elapsed while breathing from CUMA before descent, so as to keep O_2 prebreathing to a minimum. Normally this period was less.

The wet divers stood fully submerged on the wet side of the barrier while the standby diver remained semi-submerged to the waist in the intermediate area on the dry side of the barrier. Once in position, the divers emptied their counterlungs and filled them with bypass gas with a 20% O_2 content, in accordance with standard operational CUMA drills. This reduces the O_2 content of the counterlung to about 50%, thus preventing an unacceptable rise in PO_2 during descent. On completion, the DRF was pressurized.

The planned descent rate was 18 msw·min-1. However, for the first 6 msw, descent was made at 12 msw/min and the final descent rate at 18 msw/min was not started until confirmation from the CUMA diagnostics at around 6 msw that the helium flow had commenced, thus ensuring that a PO_2 of 1.6 ATA was being delivered to the breathing loop. On arrival at the planned depth of the dive, all divers inflated their counterlungs using the bypass valve until the counterlung relief valve lifted, again in accordance with CUMA drills in order to remove any PO_2 spike produced by gas concentration inertia during descent.

If time permitted, the wet divers (Red and Yellow) then moved to the bicycle ergometers (electro-magnetically braked bicycle ergometers (W. E. Collins) with pedal units modified for underwater use) and commenced exercise, pedaling at 55 to 65 rpm with the brake set at 50 watts. The exercise protocol was 5 min work followed by 5 min rest, in repeating cycles. The standby diver did not exercise but was directed to move around frequently to avoid cramped muscles and to improve circulation. When there were 2 min remaining in the bottom time, Red and Yellow Divers were instructed to get off the ergometers and position themselves in view of the underwater cameras prior to ascent.

During experimental diving, depth-time profiles often do not match the ideal calculated profiles as presented in dive tables because of interruptions in descent; consequently it is important to track the time and depth to calculate the actual decompression requirements. Therefore, a PC-based dive computer (Pentium II, with National Instruments data acquisition hardware and a custom application developed using National Instruments LabWindows Ver. 5.02 for Windows NT) was used on-line to monitor the divers' depth and calculate the decompression status from the CUMA decompression algorithm. The depth was obtained from the chamber electronic depth gauge (Heise Model # 901B) and the "Safe Ascent Depth (SAD)" was calculated, recorded and displayed on a video display monitor (Figure 1).

In the event of a delay during descent, the bottom time was extended until the SAD displayed on the dive computer reached the SAD that would have been expected for the originally planned bottom time (Table 4). This was to ensure that the gas loading would be similar to that from an uninterrupted descent. This information was provided in a printed, minute-by-minute listing of elapsed time, depth and expected SAD for that dive. The dive profile shown in Figure 1 is an example of a dive with a delay on descent with the departure from the bottom being delayed until the expected SAD was attained. For the deep, no-decompression dives and the short decompression dives, where the descent time makes up a substantial portion of the bottom time, the SAD was also used for leaving bottom.

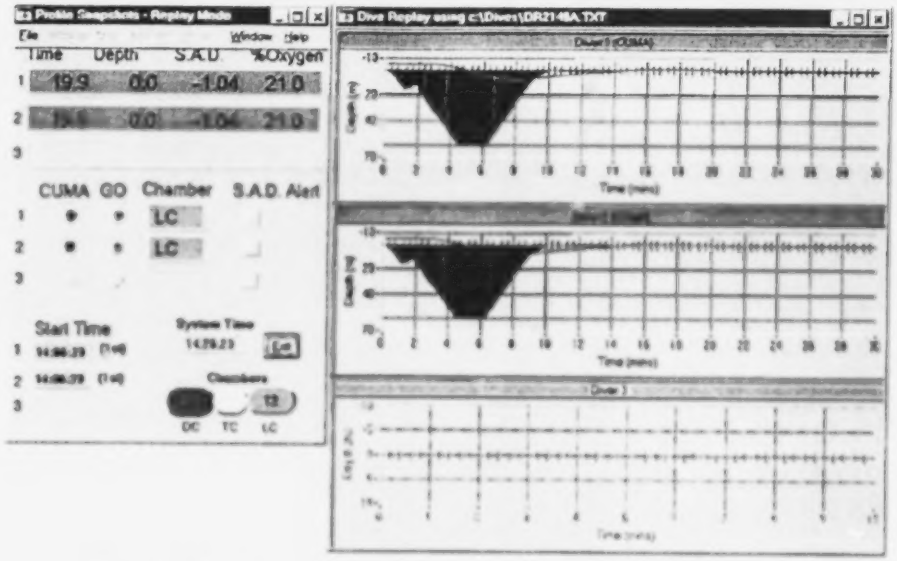

Figure 1. *PC-based dive computer display for monitoring decompression status.*

Table 4. *Predicted Safe Ascent Depths (SAD) at end of bottom time*

Depth (msw)	Time (min)	SAD (msw)	Depth (msw)	Time (min)	SAD (msw)	Depth (msw)	Time (min)	SAD (msw)
18	55	1.44	51	8	8.16	69	5	4.95
30	20	6.53	54	7	7.31	***Deep, short decompression dives***		
36	14	7.55	60	5	3.83			
42	11	8.29	60	6	6.54	72	5	5.25
45	10	8.57	63	5	4.24	72	6	8.84
48	9	8.55	63	6	7.15	75	6	9.35

Note: The expected SAD was calculated from the original CUMA decompression algorithm (used in the PC-based dive computer) and not from the modified algorithm for no-decompression diving.

For the no-decompression dives, ascent was made directly to the surface at 18 msw/min. Once on the surface, the standby and wet divers were removed from the water and undressed. All divers, including the team leader, then proceeded into the living chamber of the DRF as a precautionary measure and the first Doppler ultrasonic bubble monitoring session [16] was carried out immediately, starting with the team leader and standby diver and then the two wet divers. After Doppler monitoring was completed, all

subjects exited the chamber and after a short debriefing, left the chamber area to wait for their 20-min Doppler monitoring session.

For the deep, short dives to 72 and 75 msw dives requiring a decompression stop, ascent to the stop was at 18 msw/min. For the 72 msw/5 min dives, the stop was conducted at 9 msw followed by a direct ascent to surface. For the 72 and 75 msw/6 min dives requiring an in-water oxygen stop at 9 msw, the procedure was made to be compatible with the normal decompression procedure for CUMA, i.e., a 4-min stop (including ascent time) at 12 msw, allowing approximately 30-40 seconds to turn the diluent off prior to the move to 9 msw, followed by a switch to 100% oxygen on reaching 9 msw. On reaching surface, the same procedure as used for no-decompression dives was followed.

The second dive of the day was started 6 h after the completion of the first dive and followed the same procedures as the first dive. The first and second dives of the day constituted a "dive pair".

The goal was to ensure that there would be at least 7 pairs of dives (21 man-dives with 14 wet divers and 7 standby divers) for the primary no-decompression profiles, i.e., 45 msw/10 min, 54 msw/7 min, 60 msw/5 min, and 69 msw/5 min. All dive profiles were scattered over at least two dive series (four dive teams) to reduce subject bias so that the results for any given schedule would not be influenced by the response of a limited group of divers who might have been all "low bubblers" or "high bubblers". For the secondary no-decompression dive profiles and deep, short dives, at least two dive pairs were targeted.

3.3 Data acquisition

The partial pressure of inspired O_2 (PiO_2) and inspired CO_2 ($PiCO_2$) were continuously monitored for all subjects on CUMA for the full duration of each dive. In addition, the work rate of the wet divers on the bicycle ergometers was monitored and recorded. The PO_2 of the gas supplied to the breathing loop, as measured by the CUMA oxygen analyzer (Carleton Life Support Technologies, Inc., Part No. 1135-C), was also monitored for comparative analysis against PiO_2.

The inspired gas in the breathing loop was sampled by penetrating the right side of the scrubber housing and extending a sample line (Parflex N 1/8 inch O.D. x 0.031 inch I.D., Nylon 11 tubing) between 20 to 40 mm up the inhalation breathing hose. Electrical leads monitored the ergometer workload settings (rpm and wattage) and the CUMA oxygen analyzer PO2. The CUMA oxygen analyzer PO_2 was measured by teeing into the analyzer display cable. All gas sample lines and electrical leads from both Red and Yellow Divers and the standby diver were passed through a protective jacket of polyurethane tubing and then routed to a terminal block and diverted through the DRF hull (Figure 2).

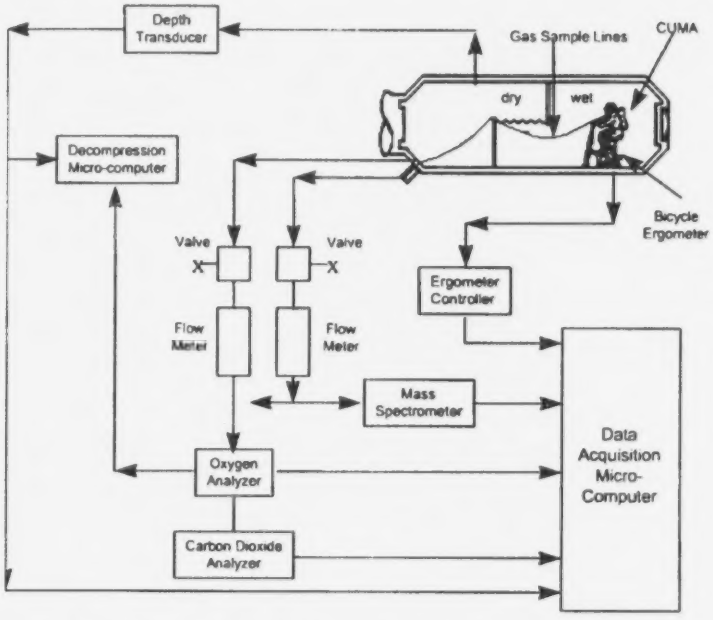

Figure 2. *DRDC Toronto DRF Wet Chamber with schematic for data acquisition system.*

Once outside the chamber, the gas samples were allowed to expand to atmospheric pressure and the samples diverted to the gas analysis instruments. The sample flow was kept constant using mass flow controllers (Brooks, Model 5850E, 0-1.0 slm air) calibrated and set between 0.40 and 0.45[2]. The PiO_2 was measured using furnace type O_2 analyzers (Ametek Oxygen Analyzer S-3A/1) and the $PiCO_2$ was measured using infrared analyzers (Analytical Development Company, PM3A).

Data from the instruments were acquired using a custom application developed in Labview (National Instruments) and HP Basic on a Sun Microsystems Ultra Sparc workstation through a IEEE 488 interface to an HP3852A Data Acquisition/Control Unit. All lines from the instruments and the electrical leads from the chamber were interfaced to the HP3852A. The PiO_2, CUMA oxygen analyzer PO_2, $PiCO_2$, ergometer workload settings, time and depth (from the electronic depth transducer, Heise Model # 901B) were sampled every 6 seconds by the HP3852A system. The analogue output of the oxygen analyzers was also displayed on the PC-based dive computer located at the Dive Control Console.)

[2] Different flows were used to synchronize the lag time for each sample line. This permitted correction of PiO_2 and $PiCO_2$ values recorded during descent and ascent.

3.4 Doppler monitoring

Doppler monitoring was conducted in the Living Chamber immediately after the end of the dive, starting with the team leader and standby diver. The two wet divers were then monitored approximately 3 min later. Monitoring and scoring of bubble signals were carried out using the Kisman-Masurel (KM) coding scheme at the precordial region and the left and right subclavian veins at rest and after movement [17]. After exiting the Living Chamber, all subjects were monitored again, commencing 20 min after surfacing, then at minutes 60 and 100. An additional reading was taken one hour before the start of the second dive at minute 300. On completion of the second dive of the day, monitoring was carried out as for the first dive, but the divers were released if the scores were decreasing after the 100-min monitoring session. After each dive and following the 20-min Doppler monitoring session, divers took a warm shower for between 5 to 10 min.

For the evaluation of decompression stress associated with a dive schedule, a criterion based on past experience has been established that for any given dive schedule, if more than 50% of the subjects were observed to have maximum Bubble Grade (BG) greater than 2 (i.e., BG = 3 and/or BG = 4) in the precordial region with the diver standing at rest, then that dive would be considered to be of high risk. The precordial region at rest was selected since that represents a relatively steady-state condition. The maximum bubble scores obtained by looking at all sites (precordial, left and right subclavian veins) and conditions (at rest or after movement) were used only to provide supplementary information about the decompression stress of individual dives. (The maximum values from all sites/conditions are generally from the precordial site after movement and occasionally from the subclavian veins and represent a transient condition.)

4. Results and discussion

Six dive series (Series 7 to 12) were conducted to test the CUMA no-decompression dive profiles and the deep, short in-water decompression dives. A total of 57 volunteer divers participated as subjects and team leaders. For the majority of dive days, dives were repeated after 6 h to ensure that they could be done again as new dives. The first and second dives of the day constituted a "dive pair". Table 5 is a summary of the dive profiles tested by dive series showing the number of dives and the number of wet and standby divers who participated in the dives. Only those team leaders who breathed from a CUMA set are shown.

Table 5. *Dive Series and Dives Conducted*

Series	Date	Dive (msw/min)	# Dives	# Wet divers	# Stdby divers	# Team Ldrs[1]	Comments	# Valid man-dives
7(IH[2])	9-18 Nov 99	60/5	7	14	7	0	One single dive only	21
7	22 Nov – 17 Dec 99	60/5	12	22	12	1	One first dive aborted, ear problems	32
		69/5	4	8	4	4		16
8(IH)	25-27 Apr 00	69/5	2	2	2	2	Single dives only	6
8	1-26 May 00	69/5	14	28	14	14		56
		45/10	8	16	8	8		32
		54/7	6	12	6	6		24
9	6 Nov – 1 Dec 00	45/10	6	12	6	6	One 2nd dive, new wet diver	24
		54/7	8	16	8	6		30
		60/6	4	8	4	4		16
10	12 Feb – 9 Mar 01	60/6	6	12	6	6	One 1st dive aborted, ear problems	20
11(IH)	15 Nov 01	48/9	2	4	2	2		8
11	19 Nov – 14 Dec 01	51/8	4	8	4	2		14
		63/6	1	2	1	0	Only one dive, Standby with DCI	3
		63/5	2	4	2	0	See text	6
		72/5a,b,c,d	12	22	12	0	See text for details on versions. One 2nd 72/5a dive aborted, ear problems	31
12(IH)	17 Jan 02	36/14	1	1	1	1	Single dive only	3
12	21 Jan – 15 Feb 02	18/55	2	4	2	0	First dives only, 2nd dives were 36/14	6
		30/20	2	4	2	2	2nd dive done as 30/18, new Standby	8
		36/14	4	8	4	4	2 dives – 6 hrs after 18/55 1st dive	16
		42/11	3	6	3	0	One dive – single dive only	9
		48/9	2	4	2	0		6
		72/5d	2	4	2	0		6
		72/6	5	10	5	0	1 dive done as 2nd dive after 75/6b	15
		75/6a	4	8	4	0	See text for details	12
		75/6b	5	10	5	0	One dive followed by 72/6	15
		Totals	128	249	128	68		435

Note 1. For each dive, there is a Team Leader. However, only those Team Leaders who were using CUMA are shown.

2. IH indicates that dives were done at EDU with in-house divers prior to the main series with visiting divers.

During Series 7, 9, 10, and 11, no-decompression dives were tested in conjunction with those for verifying repetitive diving for surface decompression with O_2 after a 3 h surface interval [5]. During Series 11 and 12, the short in-water decompression dives to 72 and 75 msw were tested in addition to no-decompression dives. Table A2, Annex A, shows dives that were conducted each day. The subjects and team leaders in each dive are also shown. These constituted 47 no-decompression dive pairs (45 carried out successfully), six single no-decompression dives, and 14 deep, short decompression dive pairs (13 carried out successfully). For the deep short dives, team leaders breathed 75% He/25% O_2 and were not counted as dive subjects. A total of 505 man-dives were conducted with 435 on CUMA that could be used for validation.

4.1 Description of dive series

Testing commenced in Series 7 with eight subjects (FDU(P) – 1, RAN – 1, RN – 3, RNZN – 2, Poland – 1) and four DRDC Toronto team leaders. Eight no-decompression dive pairs were conducted, one of which resulted in ear problems on the first dive and was not used. Prior to the series, DRDC Toronto divers carried out three dive pairs and one single dive (shown as Series 7(IH) in Table 5). For the majority of these dives, team leaders breathed 75% He/25% O_2. When the CUMA V2 set became available, team leaders started using this set to provide additional data for validating CUMA no-decompression limits. Team leaders only did one dive of each dive pair, with a different team leader for the second dive.

Series 8 was devoted completely to no-decompression dives with six subjects (RN – 4, RNZN – 2) and three DRDC Toronto team leaders. Fourteen dive pairs were carried out successfully. Two single dives were carried out by the three DRDC Toronto divers prior to the series (Series 8(IH)). For this series, the team leaders wore the CUMA V2 set and participated in both dives each day; hence their dives were also counted as valid dive pair data.

Series 9 was conducted with 10 subjects (FDU(A) – 1, FDU(P) – 1, RAN – 1, RN – 5, RNZN – 2), three DRDC Toronto team leaders, and one team leader from FDU(A). One of the DRDC Toronto team leaders also participated as a dive subject. Nine no-decompression dive pairs were carried out. Team leaders wore the CUMA V2 set, participating in both dives each day so their dives could be used as valid data. The Doppler results for 60 msw/5 min and 69 msw/5 min previously carried out in Series 7 and 8 seemed to indicate that the no-decompression limit at 60 msw could be extended to 6 min. Thus, 60 msw/6 min was added for testing in this series.

Series 10 was conducted primarily for completing the 3-h surface interval SurD O_2 repetitive dive trials [5]. As a result, only three no-decompression dive pairs were carried out. In the first dive pair, the first dive was aborted because of ear problems. Seven subjects (FDU(A) – 1, FDU(P) – 1, RN – 3, RNZN – 2) and two DRDC Toronto team leaders participated. One of the visiting dive subjects also participated as a team leader. The team leaders used CUMA V2 and their dives were counted as valid data. These dives completed the testing of the primary no-decompression profiles.

Series 11 was conducted with eight subjects (FDU(P) – 2, RN – 3, RNZN – 2, USNEDU – 1) and four DRDC Toronto team leaders. Originally, 9 no-decompression dive pairs (secondary dive profiles) were planned. However, half way through the series, the CUMA V2 prototype failed resulting in a loss of 3 dive days. Only 4 no-decompression dive pairs were carried out successfully, with the first (48 msw/9 min) being carried out with DRDC Toronto divers before the main series began (Series 11(IH). Two dive pairs were carried out at 51 msw/8 min. Although 5 dive pairs on 63 msw/6 min were planned, only two dive pairs could be re-scheduled once diving recommenced following the V2 failure. On the first dive pair attempted, one subject had DCS on the first dive and the second dive of that day had to be cancelled. The no-decompression limit at 63 msw was then changed to 5 min and was tested as the final no-decompression dive pair of this series. Six dive pairs were also conducted (5 successfully) for testing deep short dives with a brief in-water decompression stop at 9 msw. After the failure of the CUMA V2 set, team leaders returned to breathing a constant fraction HeO_2 mix (84% He-16% O_2) and performing only one dive a day.

Series 12 was carried out with six subjects (DRDC Toronto – 1, FDU(A) – 1, FDU(P) – 2, RNZN – 2) and six DRDC Toronto team leaders. Two of these team leaders also participated as dive subjects. Miscellaneous dive profiles were conducted to test no-decompression limits at the shallower depths. Six dive pairs and one single dive were carried out. One single dive was conducted prior to the series with DRDC Toronto divers (Series 12(IH)). Team leaders breathed 75% He/25% O_2 for the 42 and 48 msw dives. For the 30 and 36 msw dives, team leaders breathed from a production CUMA set and for the 18 msw dive, team leaders breathed air. Eight dive pairs were carried out for the deep short dives to 75 and 72 msw with a brief in-water decompression stop at 9 msw. Team leaders in these dives breathed 75% He/25% O_2.

4.2 Decompression illness

No DCI was observed after the second dive of any dive pair.

One case of DCI occurred after a 63 msw/6 min first dive in Series 11. On this dive, a delay was encountered during descent with one of the wet divers having ear problems. As a result, 63 msw was not attained until 4.3 min elapsed time and surfacing from the dive was delayed until 6.5 min when the dive computer indicated that the SAD was equivalent to the originally planned dive. On reaching the surface, the subject was undressed and proceeded to the Doppler monitoring station in the Living Chamber. The subject had Grade 2 precordial bubbles at rest and Grade 3 with movement. (The two wet divers had only Grade 1 bubbles in the subclavian veins and none in the precordial region.) Prior to exiting the chamber, the subject felt unwell, was pale, nauseous, and fatigued. During the neurological exam, symptoms of numbness, tingling and weakness appeared on his right arm and leg and the subject was unable to stand without support. Treatment Table 6 was initiated immediately and 3 min into the first oxygen period, he had complete resolution of all symptoms.

4.3 Time-Weighted Average PO_2

In trying to achieve the enhanced no-decompression limits for CUMA dives, calculations based on the modified CUMA decompression algorithm indicated that PO_2 values had to be around 1.1 to 1.2 ATA at the shallower depths and about 1.3 ATA for the deeper depths. As indicated in the Background, TWA PO_2 values were estimated for these enhanced no-decompression limits by mathematically simulating no-decompression dives from PO_2 values obtained in previously conducted dives with longer bottom times [3-5] to see whether or not the required PO_2 values could be attained. Table 6 shows that the mean TWA PO_2 values (from the start of the dive to the end of the bottom time) observed for wet divers in the dives done in Series 7 to 12 are in good agreement with the mean values that were estimated from previously carried out CUMA dives (Table 2). Thus, in practice, the TWA PO_2 values are sufficient to allow diving to the enhanced no-decompression limits.

Table 6. *Time-Weighted Average PO_2 (to end of Bottom Time) for Wet Divers*

Profile (msw/min)	Observed		Calculated		Profile (msw/min)	Observed		Calculated	
	PO_2 (ATA) Mean ± SD	N	PO_2 (ATA) Mean ± SD	N		PO_2 (ATA) Mean ± SD	N	PO_2 (ATA) Mean ± SD	N
18/55	1.31 ± 0.07	4			60/5	1.35 ± 0.10	35	1.33 ± 0.12	140
30/20	1.19 ± 0.01	3	1.12 ± 0.06	24	60/6	1.39 ± 0.08	17	1.35 ± 0.11	140
36/14	1.21 ± 0.11	10	1.20 ± 0.20	4	63/5	1.32 ± 0.07	6	1.41 ± 0.11	24
42/11	1.13 ± 0.08	6	1.13 ± 0.07	14	69/5	1.40 ± 0.11	38	1.43 ± 0.13	150
45/10	1.19 ± 0.07	28	1.17 ± 0.08	93	72/5	1.33 ± 0.10	24	1.41 ± 0.11	12
48/9	1.21 ± 0.09	8	1.23 ± 0.08	24	72/6	1.42 ± 0.13	10	1.44 ± 0.11	12
51/8	1.28 ± 0.08	8	1.25 ± 0.08	48	75/6	1.47 ± 0.11	18	1.45 ± 0.14	43
54/7	1.34 ± 0.07	28	1.30 ± 0.08	48					

Table A3 in Annex A shows the mean and standard deviation of the TWA PO_2 for all profiles done in Series 7 to 12 for both wet and standby divers. The maximum and minimum PO_2 values observed up to the end of the bottom time are also shown. For the shallower dives, there is a difference between the wet and standby divers since the wet divers are working. For dives deeper than 51 msw, the bottom time is not long enough to allow the wet divers to carry out any significant work. Hence there is no real difference between the TWA PO_2 for the wet and standby divers.

4.4 Doppler results

Table A4 in Annex A shows the maximum post-dive Bubble Grades (BG) observed for the primary no-decompression dive profiles tested. The number of subjects having maximum BG of 0, 1, 2, 3, and 4 for the precordial location at rest, the precordial after the movement condition, and from all sites, regardless of location (precordial or

subclavian) or condition (rest/movement) are shown. Table A5 summarizes the data for the precordial region at rest and from all sites by grouping the data into the number of divers who had observable bubbles (BG > 0) and those who had high bubble scores (BG > 2). Tables A6 and A7 show the Doppler results and the summary of those with bubbles for the secondary no-decompression profiles.

For the deeper depths (60 msw or greater), bubbles, if present post-dive, were most likely to be observed at the first Doppler session immediately after surfacing (within 8 min) or at the second Doppler session at 20 min. Bubbles disappeared quickly. In some cases, if bubbles were detected immediately after surfacing, they were gone by the second monitoring session. In other cases, where bubbles continued on into the second session or were first observed during the second session, bubbles were gone by the third session at 60 min. Bubbles, if observed on the 60 and/or 100 min sessions, were almost always at the Grade 1 level and in the subclavian veins rather than in the precordial region.

The pattern was slightly different on the shallower dives where the bottom times were longer. Bubbles, if observed, more often peaked at the 20 min session. On a few occasions, Grades 2 and/or 3 bubbles were observed at the 60 min Doppler session. On a number of occasions, bubbles were not observed during the first two Doppler sessions but were observed at the 60 or 100 min sessions for the first time. These were almost always at the Grade 1 level and were observed in the precordial region as well as in the subclavian veins.

The first no-decompression dives (3 dive pairs and a single dive to 60 msw/5 min) were done in-house prior to the start of Series 7. As shown in Table A2, only four subjects participated in these dives. Three of the subjects participated in all three dive pairs in the same role. The two wet divers (both over age 40) also participated in the single dive. One of the wet divers had bubbles on 6 of his 7 dives (Grade 3 precordial bubbles after three of the four first dives and once on a second dive, and Grades 1 and 2 bubbles on the other two). The other wet diver had bubbles on only two of his 7 dives (Grades 1 and 2, respectively) and the standby diver had no precordial bubbles on any of his 6 dives. This demonstrates the problems that can occur with a limited subject population and how the results can be skewed by one person's data. Thus it is important to have a sufficient number of subjects to get a better representation of the response to decompression stress. Some compromises will have to be made since it is impossible or impractical to be able to use subjects only once for a given dive profile.

Eight other subjects participated in the 60 msw/5 min dives done in Series 7. With the exception of one subject who had Grade 2 at rest and 3- after movement, all the other dives resulted in no observable bubbles or Grade 1 bubbles at the most in the precordial region. One diver had Grade 3 bubbles in the shoulder and two others had Grade 2 in the shoulders. Based on these results and those from the 69 msw/5 min dives, it appeared that dives to 60 msw/5 min were relatively conservative and that it might be possible to extend the no-decompression limit at 60 msw to 6 min. These dives were conducted successfully in Series 9 and the no-decompression limit for 60 msw was subsequently set for 6 min.

The success of the 60 msw/6 min trials prompted an attempt to determine whether or not a 6 min bottom time could be used at 63 msw. However, the first 63 msw/6 min dive attempted resulted in the standby diver having a serious case of neurological DCI after the first dive (see Section 4.2). Only one Doppler session was carried out since the other two subjects and the team leader were recompressed to 18 msw along with the patient as a precautionary measure even though they had no bubbles in the precordial region and only Grade 1 bubbles in the subclavian veins. These other subjects were then locked out after one 20 min oxygen period at 18 msw and returned to surface. Although there appeared to be some predisposing factors in the DCS case such as pre-dive fatigue and dehydration, it was felt more prudent to cut back the no-decompression limit to 5 min for 63 msw.

This incident demonstrated that for deep no-decompression dives, the onset of DCI symptoms may be rapid and conditions can deteriorate very quickly. One dive pair was conducted to 63 msw/5 min with no observable bubbles in the precordial region (rest or after movement). Although 5 dive pairs were originally planned for the 63 msw/6 min dive, no further trials were conducted after the decision was made to change the no-decompression time to 5 min at 63 msw as many dives had already been carried out safely to 69 msw for 5 min.

As stated in the procedures, only two dive pairs were planned for the secondary dives, primarily to confirm that the selected no-decompression times appeared to be reasonable. More dives on these profiles could not be carried out because of time constraints and subject availability. Also for some of these dives, the team leader could not be used as a subject because of the loss of the CUMA V2 set. Because of the limited subject pool during these dives and having to repeat the same dives with the same subjects, the results may not be representative of trials carried out with a larger number of subjects. For the 51 msw/8 min dives, for example, it appears that two of the four wet divers had BG > 2 for both first and second dives and the others had no observable bubbles. In fact, the same team of two wet divers dived in both dive pairs with one having BG > 2 in all dives and the other having no bubbles in all the dives. As in the results for the in-house trials carried out for 60 msw/5 min, the results are skewed because of the limited diver pool.

Only one dive pair was carried out at 30 msw. Because both wet divers had BG > 2 on the first dive with a bottom time of 20 min, the second dive was carried out for 18 min bottom time. Two dive pairs were carried out with a first dive of 18 msw/55 min and the second at 36 msw/14 min.

The Doppler results have been combined for dives from 30–51 msw and for 54–69 msw. These are shown in Tables 7 and 8, respectively. The wet, standby, and team leaders are treated separately. The results show the number of subjects with bubbles (BG > 0) and the number with high bubble scores (BG > 2) for first dives (Dive 1) and second dives (Dive 2). First dives also include those who did single dives only. In the second dive group, all subjects had previously done a first dive.

Table 7. *Summary of Doppler Results for 30 – 51 msw NOD Dives*

Role	Dive No.	No. of man-dives	Precordial Rest		Prec. Move		All Sites Max.		DCS
			BG > 0	BG > 2	BG > 0	BG > 2	BG > 0	BG > 2	
Wet Divers	1	32	13	8	17	11	23	11	0
			40.6%	25.0%	53.1%	34.4%	71.9%	34.4%	0
	2	27	11	2	16	9	17	9	0
			40.7%	7.4%	59.3%	33.3%	63.0%	33.3%	0
Standby Divers	1	17	2	1	6	1	9	2	0
			11.8%	5.9%	35.3%	5.9%	52.9%	11.8%	0
	2	13	4	0	6	2	10	2	0
			30.8%	0.0%	46.2%	15.4%	76.9%	15.4%	0
Team Leaders	1	14	2	1	4	1	5	1	0
			14.3%	7.1%	28.6%	7.1%	35.7%	7.1%	0
	2	11	1	0	4	0	6	0	0
			9.1%	0.0%	36.4%	0.0%	54.5%	0.0%	0
All divers	1	63	17	10	27	13	37	14	0
			27.0%	15.9%	42.9%	20.6%	58.7%	22.2%	0
	2	51	16	2	26	11	33	11	0
			31.4%	3.9%	51.0%	21.6%	64.7%	21.6%	0

Table 8. *Summary of Doppler Results for 54 - 69 msw NOD Dives*

Role	Dive No.	No. of man-dives	Precordial Rest		Prec. Move		All Sites Max.		DCS
			BG > 0	BG > 2	BG > 0	BG > 2	BG > 0	BG > 2	
Wet Divers	1	63	11	0	19	3	38	5	0
			17.5%	0.0%	30.2%	4.8%	60.3%	7.9%	0
	2	59	10	1	16	2	29	3	0
			16.9%	1.7%	27.1%	3.4%	49.2%	5.1%	0
Standby Divers	1	32	4	1	8	1	18	2	0
			12.5%	3.1%	25.0%	3.1%	56.3%	6.3%	0
	2	31	4	0	6	0	21	2	0
			12.9%	0.0%	19.4%	0.0%	67.7%	6.5%	0
Team Leaders	1	22	2	1	3	2	7	2	0
			9.1%	4.5%	13.6%	9.1%	31.8%	9.1%	0
	2	19	3	0	3	1	8	1	0
			15.8%	0.0%	15.8%	5.3%	42.1%	5.3%	0
All divers	1	117	17	2	30	6	63	9	0
			14.5%	1.7%	25.6%	5.1%	53.8%	7.7%	0
	2	109	17	1	25	3	58	6	0
			15.6%	0.9%	22.9%	2.8%	53.2%	5.5%	0

The results for team leaders seem to be slightly lower than those for the standby divers. For the shallow dives, there is a distinct difference between the results for the wet divers who were working on the bicycle ergometer and the standby and team leaders who were not. This difference is not as great between the wet and the other divers for the deeper

dives since the wet divers had no time to work. As indicated earlier, the TWA PO_2 for the wet and standby divers are similar for the deep dives where work on the bottom is not involved.

Tables 7 and 8 also show a comparison of the Doppler results for the first and second dives. Overall, the results are similar and there was no apparent difference between the first and second dives. A better way of looking at the Doppler results is to look at the difference in bubble scores between the first and second dives for each individual subject in which the first and second dives were identical. These differences can then be grouped into individuals whose bubble scores changed by up to one, two, three or four bubble grades greater or lesser than the bubble scores during the first dive[3].

The advantage of this approach is that the differences between "low bubblers", "moderate bubblers" and "high bubblers" are minimized. Similarly, the differences between the wet working divers and resting standby divers, who generally have lower bubble scores than the wet divers, are also minimized.

The differences between the first and second dives can be used to illustrate the importance of the need for a large subject pool and a wide range of ages for testing dive profiles. Figure 3 shows results for post-dive bubbles (precordial at rest and after movement and maximum BG for all sites and conditions) observed after the 60 msw dives that were described previously. As mentioned earlier, all three dive pairs done in the pre-Series 7 in-house dives were done by three divers. All the changes observed in the precordial region resulted from the two wet divers who were both over 40 years old. On the other hand, the standby diver (age 32.2 years) had no precordial bubbles after any of his dives, and thus had no change in bubble scores.

After the 60 msw/5 min dives done in Series 7, with a larger and younger subject group (19 subjects, average age 35.6 years), the results were quite different from the in-house dives. There was essentially no difference between the first and second dives. Similarly, the 60 msw/6 min (13 subjects, average age 32.2 years) showed little difference between the first and second dives.

Figure 4 shows the difference between the first and second dives for the rest of the primary dives. Because many subjects had bubbles in the 45 msw/10 min dives, there is a larger spread in the differences between the first and second dives but they are not significantly different. The Wilcoxon signed rank test applied to the primary dives (excluding the in-house dives to 60 msw/5 min) showed that there were no significant differences between the first and second dives for all the primary dives. This is a non-parametric test similar to a paired-t test but better suited for categorical data such as bubble scores.

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[3] BG are recorded in steps of one-third, i.e., 1-, 1, 1+, 2-, 2, 2+, 3-, 3, 3+, 4-, 4. These can be transformed into 2/3, 1, 1 1/3, 1 2/3, 2, 2 1/3, ... to obtain the difference between the first and second dive BGs. These differences were then grouped so that a change of one BG higher would represent a change of 2/3, 1 or 11/3. A 0 change would be represented by –1/3, 0, or 1/3, e.g., a diver who had BG 3 on the first dive and BG 3-, 3, or 3+ on the second dive would be recorded as having a 0 change.

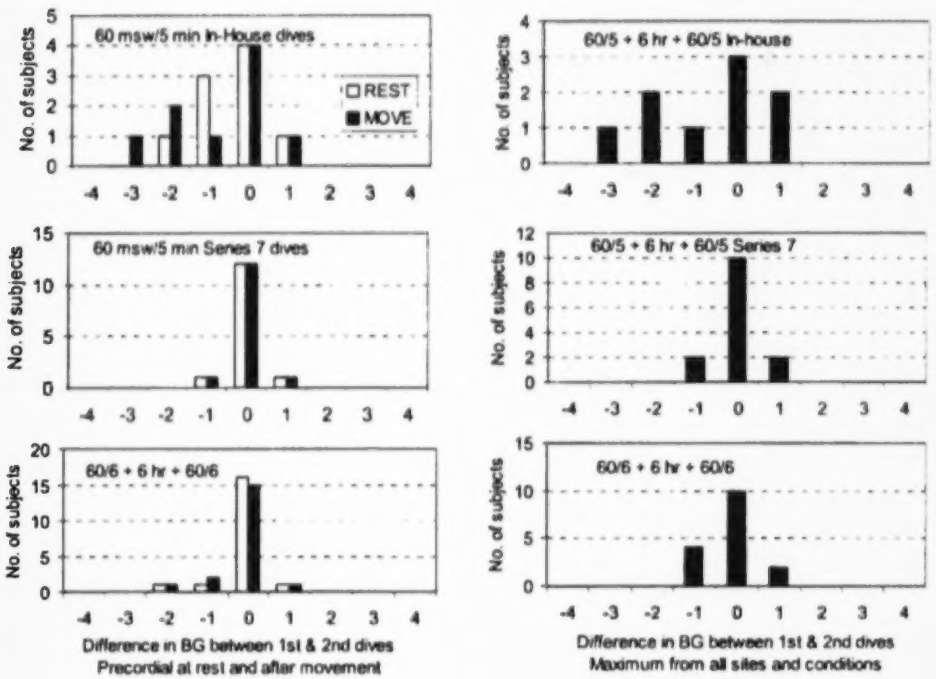
60 msw/5 min In-House dives
REST
MOVE
No. of subjects
60/5 + 6 hr + 60/5 In-house
60 msw/5 min Series 7 dives
60/5 + 6 hr + 60/5 Series 7
60/6 + 6 hr + 60/6
60/6 + 6 hr + 60/6
Difference in BG between 1st & 2nd dives
Precordial at rest and after movement
Difference in BG between 1st & 2nd dives
Maximum from all sites and conditions

***Figure 3.** Difference in Bubble Grades between 1st and 2nd dives for 60 msw NOD dives*

It should be noted that calculations from the model show that there is still some residual helium left after 6 h. This does not seem to be sufficient to significantly increase the risk of a second dive after 6 h. However, this residual helium could be a factor if a third dive were to be conducted after another 6 h. The same is true for CUMA dives requiring decompression [4]. Although 6 h is sufficient to allow divers to continue diving as a new diver on CUMA, the residual helium may increase the risk of diving a third time.

Since only a few dives were conducted on each of the secondary profiles, the results were combined with the results of the primary dives and divided into the two groups that were used in Tables 7 and 8, i.e., for dives from 30–51 msw and 54–69 msw. The differences in BG between the first and second dives for these groupings are shown in Figure 5. The in-house dives to 60 msw/5 min have been excluded from the 54–69 msw range. The differences between the first and second dives are not significant.

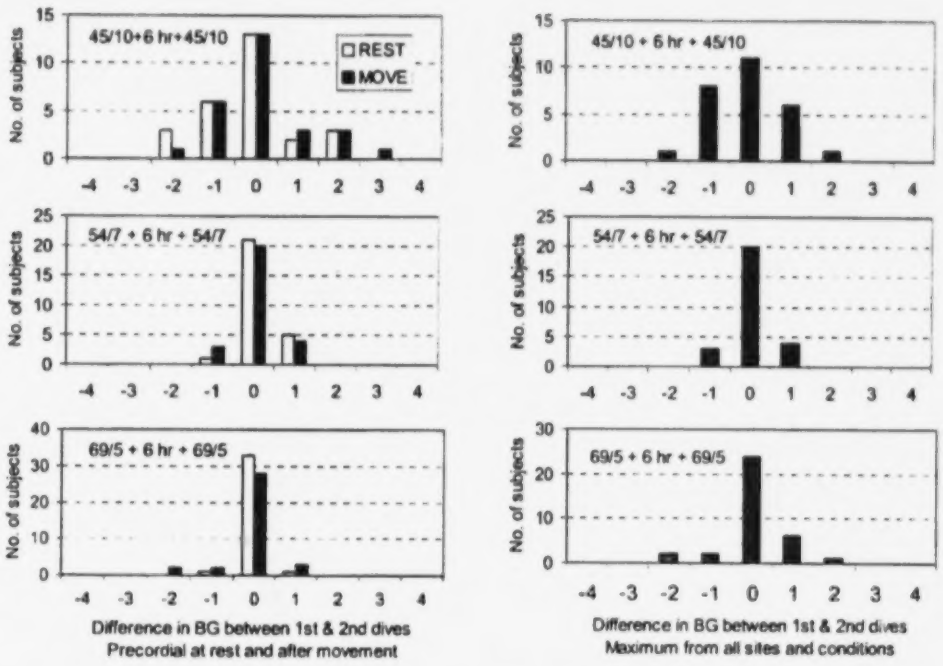
45/10+6 hr+45/10
REST
MOVE
45/10 + 6 hr + 45/10
54/7 + 6 hr + 54/7
69/5 + 6 hr + 69/5
No. of subjects
Difference in BG between 1st & 2nd dives
Precordial at rest and after movement
Maximum from all sites and conditions

Figure 4. *Difference in Bubble Grades between 1st and 2nd dives for 45, 54 and 69 msw NOD dives*

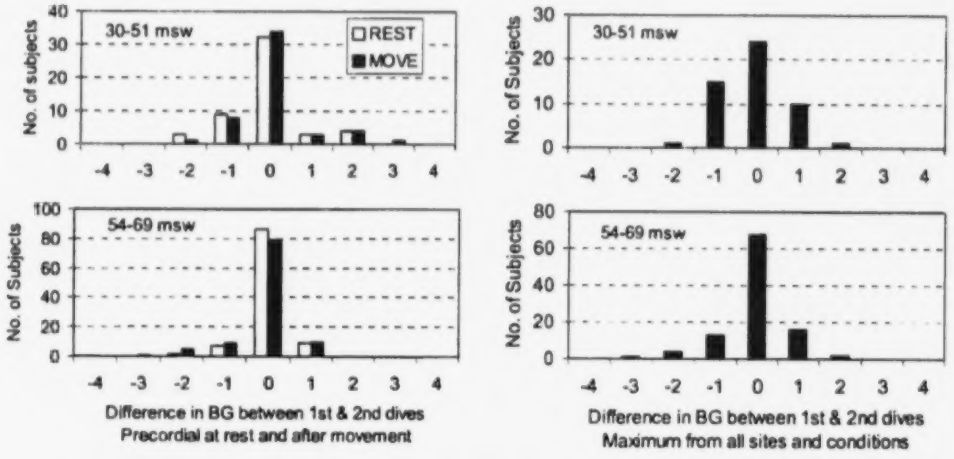

Figure 5. *Difference in Bubble Grades between 1st and 2nd dives*

The results shown in Figure 5 are for dive pairs where the second dives were identical to the first dives. Figure 6 shows the results from two dive pairs where the first and second dives were not identical, with a first dive of 18 msw/55 min followed by a second dive after 6 h to 36 msw/14 min. For this situation, four out of six divers had higher bubble scores on the second dive. On the other hand, a dive to 36 msw/14 min (four subjects) followed by another dive to 36 msw/14 min after 6 h showed no precordial bubbles on either the first or second dives. One of the subjects, however, had Grade 1 bubbles in the shoulders in the first dive and none on the second (also shown in Figure 6). Whether or not these results suggest that the residual helium from a shallow long bottom time no-decompression dive is influencing the second dive more than when the first and second dives are identical is difficult to say since only a limited number of trials were carried out. Calculations show that any reduction in the second dive no-decompression limit should be only a few percent at the most. This question may be academic since operationally, such shallow long bottom time no-decompressions dives would not likely be carried out on CUMA.

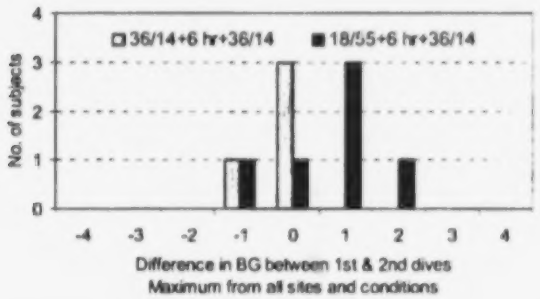

***Figure 6.** Differences between a first long NOD dive and second dives*

4.5 Deep, short decompression dives

Table A8, Annex A, shows the Doppler results for the deep, short-decompression dives. Table 9 is a summary of the results showing the number of divers with bubbles (BG > 0) and those with high bubble scores (BG > 2). The wet and standby divers have been combined as the mean TWA PO_2 for wet and standby divers were the same (Table A3). These dives were all done on the SAD to compensate for any departure from a descent rate of 18 msw/min.

From the modified CUMA model, calculations for diving to 72 msw/5 min with a TWA PO_2 of 1.2 ATA showed that a short decompression stop of only a few minutes at 3 msw seemed to be adequate. To be conservative, the initial dive (72/5a) was set for a 5-min in-water stop on O_2 at 9 msw. However, the procedure tested of switching the diluent off at 9 msw, conducting an O_2 flush and starting the O_2 stop time once it was established

from the external monitoring that the O_2 level was above 90% added several minutes to the time actually spent at 9 msw (average of 8.1 min). This procedure resulted in a very conservative dive with observed bubbles being minimal. The profile was then changed so that the total time spent at 9 msw (including switching the diluent off and conducting an O_2 flush) was only 5 min (72/5b), i.e., the stop time started on arrival at 9 msw, not on confirmation of an O_2 change-over. As these results showed that the profile was still conservative, the time spent at 9 msw was further reduced to 3 min (72/5c). The final change made was to remain at 9 msw for 3 min without switching the diluent off (72/5d). This also provided adequate decompression.

Table 9. *Doppler Results for Deep, Short Decompression Dives*

Profile (msw/min)	Dive No.	Wet and Standby Divers				Profile (msw/min)	Dive No.	Wet and Standby Divers			
		Precordial rest		All sites max.				Precordial rest		All sites max.	
		BG >0	BG>2	BG >0	BG>2			BG >0	BG>2	BG >0	BG>2
72/5a	1	0/6	0/6	2/6	1/6	72/6	1	0/6	0/6	3/6	0/6
	2	0/2	0/2	0/2	0/2		2	1/9	0/9	4/9	1/9
72/5b	1	0/6	0/6	3/6	0/6						
	2	0/5	0/5	3/5	0/5						
72/5c	1	0/3	0/3	3/3	0/3	75/5a	1	0/6	0/6	2/6	0/6
	2	1/3	0/3	3/3	0/3		2	0/6	0/6	1/6	0/6
72/5d	1	0/6	0/6	4/6	0/6	75/5b	1	1/9	0/9	3/9	0/9
	2	1/6	0/6	5/6	0/6		2	0/6	0/6	1/6	0/6

Notes:
1. 72/5a –stop at 9 msw, switch to O_2, remain for 5 min after confirmation of O_2 switch
2. 72/5b – stop at 9 msw, close diluent valve, remain for 5 min
3. 72/5c – stop at 9 msw, close diluent valve, remain for 3 min
4. 72/5d – stop at 9 msw, remain 3 min with no gas switch
5. 72/6 – 4 min stop at 12 msw (including ascent time), 4 min on O_2 after confirmation of O_2 switch
6. 75/6a – 4 min stop at 12 msw (including ascent time), 10 min on O_2 after confirmation of O_2 switch
7. 75/6b – 4 min stop at 12 msw (including ascent time), 6 min on O_2 after confirmation of O_2 switch

For diving to 75 msw, a bottom time of 5 min was not practical since the actual time spent on the bottom, allowing for a 18 msw/min descent rate, would not allow much useful working time. Thus, a bottom time of 6 min was selected. Calculations (for a TWA PO_2 of 1.2 ATA) showed that a decompression stop of approximately 10 min total at 6 and 3 msw would be required. To be conservative, this was changed to an O_2 stop of 10 min at 9 msw. In addition, the decompression was made to be compatible with the standard operating procedure for CUMA, i.e., a 4-min stop (including ascent time) at 12 msw, allowing approximately 30-40 seconds to turn the diluent off prior to the move to 9 msw, then flushing the counterlung on arrival at 9 msw and starting the required stop time after confirmation from the external monitoring that the O_2 levels were above 90%. For the first 75 msw/6 min profile tested, with a 10 min O_2 stop specified at 9 msw (75/6a), the actual time spent at 9 msw averaged 12.6 min. The second profile tested was a 6 min O_2 stop at 9 msw (75/6b). The actual time spent at 9 msw averaged 7.9 min. This would provide more than adequate decompression considering that the actual TWA PO_2 to the end of the bottom time averages approximately 1.4 ATA.

Based on the experience gained from the 75 msw/6 min profiles, a 72 msw/6 min profile requiring a 4 min O_2 stop at 9 msw was tested. With the standard O_2 flush operating procedure, this resulted in an actual time at 9 msw of approximately 5.7 min. Although the 72 msw/5 min dive could be done with a mere 3 min decompression stop at 9 msw, it is a departure from the standard operating procedure. Since a 72 msw/6 min dive would also give more useful working time at the bottom, it was selected over the 72 msw/5 min profile.

In addition to the 63, 66 and 69 msw 5 min no-decompression bottom time, a 6 min bottom time can be used for diving at 63, 66, and 69 msw using the decompression time specified for 72 msw/6 min. Note that this gives a considerable saving in decompression time from those specified originally in CF Tables 11 and 12.

4.6 Comparison with CF Tables 10 - 12

The validation of longer no-decompression limits than those in CF Tables 10-12 and the tests done on deep short decompression dives will result in significant changes to these tables. Table B1 in Annex B shows the revised CF Table 10, CUMA No-Decompression (Version 2). These times are also shown in Table 10 below with the original no-decompression times in the present CF Table 10 for comparison. The bottom time at 12 msw has been limited to 120 min, a limitation resulting from the original endurance of the CUMA. However, with the endurance now increased to 180 min in the present version of CUMA, the 12 msw limit could also be increased. Note that for depths shallower than 42 msw, the new bottom times are still more conservative than the US Navy no-decompression limits (Table 1 in Section 2.1).

Table 10 below also shows the schedules from the present CF Table 11, in-water oxygen decompression, that are affected by the new no-decompression times and need to be changed. From 30 to 45 msw, the first two schedules at each depth in the original table will be replaced by new no-decompression limits. From 48 to 60 msw, the 6 min bottom time schedules at those depths will be replaced by new no-decompression limits. From 63 to 69 msw, a 5 min no-decompression schedule has been added and from 63 to 75 msw, the 6-min bottom time schedule will be replaced by one with a significantly shortened in-water decompression time. The decompression time tested for 72 msw/6 min has also been used for 63, 66 and 69 msw for 6 min.

Table B2 in Annex B shows the revised CF Tables 10, 11 and 12 combined into a single table. For 78 and 81 msw and for bottom times longer than those shown in Table 10, the original decompression schedules contained in CF Tables 11 and 12 have been retained. This unfortunately results in a discontinuity in the transition from the new decompression times to the original decompression times with a sudden large increase in decompression times for 10 min bottom time profiles. For example, at 51 msw, the decompression time increases from 0 at 8 min to 25 min at 10 min bottom time (an increase of only 2 min bottom time).

Table 10. Difference between original CF Tables 10 and 11 and Revised Tables

Original CUMA Table 11 Stop Times						Revised CUMA Table 11 Stop Times					
Profile (msw/min)	Bottom Time (min)	HeO_2		O_2	Total Dec. Time (min)	Profile (msw/min)	Bottom Time (min)	HeO_2		O_2	Total Dec. Time (min)
		15	12	9				15	12	9	
12	120	-	-	-	1	12	120	-	-	-	1
15	70	-	-	-	1	15	75	-	-	-	1
18	35	-	-	-	1	18	55	-	-	-	1
21	25	-	-	-	2	21	40	-	-	-	2
24	15	-	-	-	2	24	30	-	-	-	2
27	11	-	-	-	2	27	23	-	-	-	2
30	10	-	-	-	2	30	18	-	-	-	2
	20	-	4	17	22						
33	10	-	-	-	2	33	16	-	-	-	2
	15	-	4	14	19						
36	9	-	-	-	2	36	14	-	-	-	2
	15	-	4	17	22						
39	8	-	-	-	3	39	12	-	-	-	3
	10	-	4	9	14						
42	7	-	-	-	3	42	11	-	-	-	3
	10	-	4	12	17						
45	6	-	-	-	3	45	10	-	-	-	3
	10	-	4	15	20						
48	6	-	5	5	11	48	9	-	-	-	3
51	6	-	5	6	12	51	8	-	-	-	3
54	6	-	5	7	13	54	7	-	-	-	3
57	6	-	5	8	14	57	6	-	-	-	4
60	6	-	5	11	17	60	6	-	-	-	4
63	6	-	5	13	19	63	5	-	-	-	4
							6	-	4	4	9
66	6	-	6	15	22	66	5	-	-	-	4
							6	-	4	4	9
69	6	-	6	16	23	69	5	-	-	-	4
							6	-	4	4	9
72	6	-	6	18	25	72	6	-	4	4	9
75	6	5	2	19	27	75	6	-	4	6	11

The modified decompression algorithm (taking into account that the TWA PO_2 can be greater than 1.0 ATA) that was used to calculate the revised no-decompression times and the short in-water decompression stops for 72 and 75 msw could be applied to the 10 min bottom time profiles to obtain slightly shorter decompression times. Previous testing of the 10 min profiles have shown that these are low stress dives based on Doppler scores [2] and hence the decompression times could be reduced. However, any changes to the tables will require further testing.

Decompression schedules for 84, 87 and 90 msw have also been included in Table B2. Note that these schedules have never been tested but they are derived from the same model used to generate CF Tables 11 and 12. They have been included since it is necessary to have schedules deeper than the operational maximum limit (i.e., 81 msw) for emergency purposes should a diver accidentally exceed 81 msw.

4.7 No-decompression repetitive diving

Table 11 below shows repetitive no-decompression dives for surface intervals between 3 and 6 h. No dives were carried out to validate these repetitive dives. They are based on calculations from the CUMA decompression algorithm. Calculations show that the first dive no-decompression bottom times should be reduced by approximately 15% to maintain the repetitive dives as no-decompression dives. Since these times have not been tested, the repetitive no-decompression times shown in Table 11 represent about a 20% reduction. The consequent reduction in no-decompression times means that for depths greater than 57 msw, repetitive no-decompression times would not allow sufficient time on the bottom for any useful work. Thus it would be better to maintain a 5-min bottom time, but instead of ascending directly to the surface, divers should make decompression stops at 12 and 9 msw similar to those that were used for the 72 msw/6 min dives shown in Table 10 in Section 4.6.

Table 11. *Repetitive No-Decompression Times for Surface Intervals from 3 to 6 Hours (Untested)*

DEPTH (msw)	CF TABLE 10 (V. 2)	Repet No-D (calc.)	DEPTH (msw)	CF TABLE 10 (V. 2)	Repet No-D (calc.)	DEPTH (msw)	CF TABLE 10 (V. 2)	Repet No-D (calc.)
12	120	120	33	16	12	54	7	5
15	75	60	36	14	11	57	6	*
18	55	45	39	12	9	60	6	*
21	40	32	42	11	8	63	5	*
24	30	24	45	10	8	66	5	*
27	23	18	48	9	7	69	5	*
30	18	14	51	8	6	* 5-min bottom time with stops		

The repetitive no-decompression times shown in Table 11 above have been included in CF Table 14, CUMA Repetitive Dive Table for Surface Intervals from 3 to 6 Hours [5] (Table B3, Annex B). The in-water decompression stops for short repetitive dives from 57 to 69 msw are also shown in CF Table 14.

However it should be noted that during the testing of repetitive decompression-required dives with a 3-h surface interval, some individuals were found to have high bubble scores on some profiles prior to commencing the repetitive dive [5]. These dives would have a higher level of residual helium remaining from the first dive than there would be

in a no-decompression first dive. In the event of a subsequent repetitive no-decompression dive, there may be an increased risk of decompression sickness. Therefore the no-decompression profiles in CF Table 14 are only for use following a no-decompression first dive from CF Table 10-12 (Table B2, Annex B). If the first dive of a repetitive pair required decompression, the second dive must also be one that provides additional decompression time. In this case, if the second dive is required within the no-decompression entries in CF Table 14, the next incremental bottom time requiring decompression is to be used.

If it is necessary to conduct repetitive dives for surface intervals less than 3 h, then the bottom times of the first and second dives should be added together.

4.8 Multiple sequential dives

Multiple sequential no-decompression dives at 6-h intervals were not tested nor planned for testing. All testing was restricted to two dives per day. As stated earlier in Section 4.4, calculations from the model show that there is still some residual helium left after 6 h. Although this does not seem to be sufficient to significantly increase the risk of a second dive as a new diver on CUMA after 6 h, this residual helium could be a factor and may possibly increase the risk of diving a third time after another 6 h.

With CUMA dives that require decompression, there are two other factors that must be considered for multiple dives [5]. First, there is an increased risk of pulmonary oxygen toxicity with multiple dives in a short period of time [15]. Secondly, there is the fatigue factor. This is a cumulative effect that will vary between divers. There is tangible evidence to show that fatigue from diving and overall workload is a significant factor in predisposing a diver to an increased risk of decompression sickness. Operationally, it is not realistic to expect or justify the frequent requirement for continued diving over an extended period of more than 12 h without adequate rest.

Although pulmonary oxygen toxicity and fatigue may not be a problem for multiple no-decompression diving, nevertheless, the general recommendations made for multiple dives within 12 h of each other [5] should also be followed for no-decompression dives:

a. a third dive must not be conducted after the initial two dives of a dive pair until a period of 12 h has elapsed, and

b. if conducting two or more dives per day over two consecutive days, a period of 24 h must elapse before further diving.

5. Summary

The extended no-decompression dives and deep short dives with limited in-water decompression stops that have been validated during these trials provide a number of benefits, not only for operational diving on CUMA but also in terms of increased diver safety and rationalized training time. These trials, together with the 6 h surface interval studies allowing diving again on CUMA without any decompression penalties [4] and the trials to validate repetitive diving on CUMA after 3 to 6 h [5], conclude the program started in 1997 to provide enhanced diving procedures and capabilities for CUMA diving and make better use of available manpower.

During this entire program from 1997 to 2001 (including the reduced surface interval [4], repetitive dive trials [5], and the no-decompression trials), 98 different individuals participated in the dives as either subjects (wet and standby divers) and/or team leaders: FDU(A) – 9; FDU(P) – 18 (3 of these participated in more than one dive series, for a total of 21 subjects contributed by FDU(P)); RN – 28 (includes two RN Diving Officers who were posted to EDU on exchange and a third to another CF Command); RAN – 6; RNZN – 16; USN – 5; Poland – 1; and DRDC Toronto – 15 (CF members only; the two Project Officers for this program (the RN Exchange Officers mentioned above) are included in the RN totals). Most of the DRDC Toronto individuals and the two Project Officers participated in more than one dive series as both team leaders and dive subjects. A few participated only as team leaders. A total of 331 dives were carried out comprising 1300 man-dives, of which 128 dives (505 man-dives) were carried out for the no-decompression dives and deep short dives reported here. Of these, 435 man-dives on CUMA were used for validation. Only two cases of DCI were encountered, one of which occurred on a no-decompression dive.

The success of this entire program was made possible by close cooperation between DRDC Toronto (EDU), DRDC, NDHQ and the ABCANZ participants. The success of this project has highlighted the benefits and advantages of international collaboration and cooperation in the conduct of human experimental diving. In addition, the data collected during this project will be available to other participating nations for the HeO_2 database that was assembled for the Joint Development of a Common HeO_2 Decompression Probabilistic Algorithm [18].

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Annex A: Experimental data

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TABLE A1. DIVER STATISTICS

Series	Diver Code	Affiliation	Sex	Age (yr)	Weight (kg)	Height (cm)	Biceps (mm)	Triceps (mm)	Sub-scapula (mm)	Supra-iliac (mm)	BMI	% Body Fat	Tobacco # cig/day
7(IH)	84	DCIEM	M	42.0	76	168							nil
7(IH)	85	DCIEM	M	40.0	80	174							
7(IH)	52	DCIEM	M	41.5	86	169	13	13	19	26	30.1	29.45	nil
7(IH), 7	87	DCIEM	M	32.2	81	172	11	14	15	25	27.3	24.32	1 to 10
7(IH), 7	91	DCIEM	M	36.5	87	180	8	16	11	14	26.8	21.31	nil
7(IH), 7	92	DCIEM	M	35.2	96	173	11	14	27	32	32.0	27.09	nil
7	86	DCIEM	M	36.8	98	185	16	26	19	26	28.6	27.48	11 to 20
7	72	FDU(P)	M	35.1	79	169	11	14	18	19	27.6	23.82	nil
7	100	POLAND	M	40.5	93	186	5	13	12	23	26.8	25.36	nil
7	24	RAN	M	38.5	88	170	15	25	18	14	30.4	25.43	nil
7	7	RN	M	35.3	81	170	6	15	14	18	28.0	22.14	nil
7	11	RN	M	38.3	84	177	9	24	17	13	26.8	23.99	nil
7	12	RN	M	35.2	86	175	8	14	20	18	28.0	23.47	nil
7	34	RNZ	M	26.5	79	174	4	9	9	9	26.0	13.11	nil
7	35	RNZ	M	34.8	105	172	12	8	19	14	35.4	22.14	nil
8(IH), 8	86	DCIEM	M	37.3	98	185	16	26	19	26	28.6	27.48	11 to 20
8(IH), 8	87	DCIEM	M	32.6	83	172	10	15	15	20	28.0	23.47	1 to 10
8(IH), 8	91	DCIEM	M	36.9	85	180	7	10	13	16	26.2	20.64	nil
8	13	RN	M	30.7	113	187	14	23	18	23	32.3	26.29	1 to 10
8	14	RN	M	36.3	73	172	13	18	15	18	24.6	24.16	nil
8	15	RN	M	36.4	94	186	7	17	14	9	27.1	20.87	nil
8	101	RN	M	45.2	74	164	7	10	15	12	27.5	22.79	nil
8	36	RNZ	M	28.6	78	175	6	6	8	12	25.4	13.49	nil
8	37	RNZ	M	30.6	74	182	6	9	9	8	22.3	16.84	nil
9	93	DCIEM	M	34.7	75	173	11	14	14	22	25.0	23.64	1 to 10
9	94	DCIEM	M	36.6	98	179	12	19	27	30	30.5	27.60	nil
9	95	DCIEM	M	38.8	72	168	8	11	12	15	25.5	20.64	nil
9	87	FDU(A)	M	33.1	83	172	10	10	15	22	28.0	22.92	1 to 10
9	55	FDU(A)	M	32.3	92	185	9	15	12	9	26.8	20.41	nil
9	73	FDU(P)	M	32.3	87	183	6	10	12	14	25.9	19.68	1 to 10
9	25	RAN	M	25.1	73	170	7	16	8	10	25.2	16.46	1 to 10
9	16	RN	M	30.2	84	171	9	17	13	14	28.7	22.14	nil
9	17	RN	M	46.4	81	172	9	12	15	16	27.3	25.10	nil
9	86	RN	M	37.8	95	185	12	20	20	24	27.7	26.01	11 to 20
9	18	RN	M	36.9	98	182	11	19	13	10	29.5	22.14	11 to 20
9	19	RN	M	34.5	93	180	10	10	12	17	28.7	21.31	nil
9	38	RNZ	M	29.7	89	171	10	14	16	17	30.4	22.92	nil
9	39	RNZ	M	22.6	84	174	6	12	11	14	27.7	17.04	nil

TABLE A1. DIVER STATISTICS (cont'd)

Series	Diver Code	Affiliation	Sex	Age (yr)	Weight (kg)	Height (cm)	Biceps (mm)	Triceps (mm)	Sub-scapula (mm)	Supra-iliac (mm)	BMI	% Body Fat	Tobacco # cig/day
10	93	DCIEM	M	35.0	76	173	9	15	16	23	25.3	23.99	1 to 10
10	95	DCIEM	M	39.0	73	168	7	10	11	13	25.8	19.43	nil
10	56	FDU(A)	M	39.5	98	174	5	15	13	12	32.3	20.41	nil
10	70	FDU(P)	M	30.2	66	160	6	13	15	12	25.7	20.64	nil
10	111	RN	M	38.4	82	164	10	8	13	23	30.4	22.34	NIL
10	110	RN	M	27.1	82	181	6	9	17	16	25.0	18.37	nil
10	112	RN	M	28.0	85	175	16	7	11	13	27.7	18.11	NIL
10	131	RNZ	M	29.9	90	179	13	7	12	8	28.0	19.17	nil
10	130	RNZ	M	31.9	79	166	6	12	13	20	28.6	21.73	nil
11(IH), 11	71	DCIEM	M	32.0	100.0	180	6.4	10.8	23.0	16.0	30.8	17.93	nil
11(IH), 11	93	DCIEM	M	35.7	75.5	173	8.2	12.0	21.0	10.0	25.2	21.78	1 to 10
11(IH), 11	95	DCIEM	M	39.8	73.0	168	4.4	5.0	11.4	8.0	25.8	10.13	nil
11(IH), 11	97	DCIEM	M	40.7	87.8	173	11.0	12.2	16.0	13.0	29.3	17.08	nil
11	74	FDU(P)	M	25.7	93.7	179	5.0	7.2	11.4	9.8	29.2	14.00	nil
11	75	FDU(P)	M	37.6	74.4	176	2.8	3.6	7.8	5.0	24.0	11.58	nil
11	113	RN	M	32.6	71.2	169	5.8	11.6	13.0	14.2	24.9	20.31	nil
11	114	RN	M	25.5	93.4	181	10.2	10.6	13.8	10.6	28.5	17.64	nil
11	115	RN	M	29.5	71.3	172.5	7.8	7.0	8.8	8.8	23.9	16.96	nil
11	132	RNZN	M	32.2	89	185.5	5.8	7.8	10.8	6.0	25.8	16.30	nil
11	133	RNZN	M	28.4	78	180	4.6	7.0	8.8	8.4	24.0	12.24	1 to 10
11	44	USNEDU	M	38.5	80	181	4.6	5.4	9.8	8.6	24.4	15.60	nil
12(IH), 12	71	DCIEM	M	32.1	104.0	180	11.0	16.0	24.0	16.0	32.0	24.65	nil
12(IH), 12	94	DCIEM	M	37.8	92.4	179	8.5	12.5	9.5	14.5	28.8	20.41	nil
12(IH), 12	97	DCIEM	M	40.9	92.5	173	12.0	15.0	24.5	16.0	30.9	28.74	nil
12	83	DCIEM	M	49.6	78.0	169	8.0	10.4	22.4	10.6	27.3	21.82	nil
12	93	DCIEM	M	35.9	75.5	173	8.2	12.0	21.0	10.0	25.2	21.78	1 to 10
12	95	DCIEM	M	40.0	75.5	168	6.0	7.0	17.0	8.0	26.7	18.63	nil
12	98	DCIEM	M	31.7	89.0	187	3.2	9.0	15.0	9.4	25.4	18.24	nil
12	57	FDU(A)	M	30.3	76.5	172	4.0	16.0	12.0	6.0	25.8	18.63	nil
12	76	FDU(P)	M	29.9	97.0	186	4.5	7.0	19.0	8.0	28.0	18.77	nil
12	77	FDU(P)	M	30.0	76.3	172	4.5	6.5	12.0	5.5	25.7	15.63	nil
12	134	RNZN	M	29.0	82.0	171	4.0	3.5	14.0	10.0	28.0	13.30	nil
12	135	RNZN	M	23.3	85.8	175	7.5	8.0	14.0	16.0	28.0	17.72	nil

TABLE A2. DIVES CONDUCTED DURING SERIES 7-12

Date	Series	Dive Prof	Ser No	Diver Identification				SI	Dive Prof	Ser No	Diver Identification				Comments
				Wet R	Wet Y	Stdby	TL				Wet R	Wet Y	Stdby	TL	
11/09/99	7(HI)	60/5	DR1990A	91	52	84	**87**								NoD. In-house
11/10/99	7(HI)	60/5	DR1991A	52	84	87	**91**	6	60/5	DR1992R	52	84	87	**88**	NoD. In-house. TL diff
11/16/99	7(HI)	60/5	DR1993A	52	84	87	**91**	6	60/5	DR1994R	52	84	87	**92**	NoD. In-house. TL diff
11/18/99	7(HI)	60/5	DR1995A	52	84	87	**91**	6	60/5	DR1996R	52	84	87	**92**	NoD. In-house. TL diff
11/25/99	7	60/5	DR2000A	7	72	35	**91**	6	60/5	DR2001R	7	72	35	**86**	NoD. TL diff
11/26/99	7	60/5	DR2002A	34	24	11	**87**	6	60/5	DR2003R	34	24	11	**91**	NoD. TL diff
11/29/99	***7***	***57/4***	***DR2004A***	***11***	***100***	***12***	**87**	6	60/5	DR2005R		100	11	86	1st dive abort IWO2. 2nd NoD - TL on CUMA
12/02/99	7	60/5	DR2010A	12	35	34	**87**	6	60/5	DR2011R	12	35	34	**86**	NoD. TL diff
12/06/99	7	60/5	DR2012A	35	100	12	**86**	6	60/5	DR2013R	35	100	12	**91**	NoD. TL diff
12/09/99	7	60/5	DR2018A	7	24	11	**87**	6	60/5	DR2019R	7		11	**91**	NoD. TL diff. Stdby to YD
12/13/99	7	69/5	DR2020A	7	12	11	86	6	69/5	DR2021R	7	12	11	92	NoD. TL diff. TL on CUMA V2
12/16/99	7	69/5	DR2026A	24	35	34	87	6	69/5	DR2027R	24	35	34	87	NoD. TL on CUMA V2
04/25/00	8(HI)	69/5	DR2029A		91	87	86								NoD. TL on CUMA V2. in house
04/27/00	8(HI)	69/5	DR2032A		91	87	86								NoD. TL on CUMA V2. in house
05/03/00	8	69/5	DR2035A	**14**	13	15	86	6	69/5	DR2036R	**14**	13	15	86	NoD. TL on CUMA V2
05/04/00	8	69/5	DR2037A	**37**	36	**14**	91	6	69/5	DR2038R	**37**	36	**14**	91	NoD. TL on CUMA V2
05/05/00	8	69/5	DR2039A	13	15	**37**	86	6	69/5	DR2040R	13	15	**37**	86	NoD. TL on CUMA V2
05/08/00	8	69/5	DR2041A	**36**	14	13	91	6	69/5	DR2042R	**36**	14	13	91	NoD. TL on CUMA V2
05/09/00	8	69/5	DR2043A	**15**	37	**36**	87	6	69/5	DR2044R	**15**	37	**36**	87	NoD. TL on CUMA V2
05/10/00	8	69/5	DR2045A	**14**	13	**15**	86	6	69/5	DR2046R	**14**	13	**15**	86	NoD. TL on CUMA V2
05/11/00	8	69/5	DR2047A	37	36	**14**	91	6	69/5	DR2048R	37	36	**14**	91	NoD. TL on CUMA V2
05/15/00	8	45/10	DR2049A	**13**	15	37	86	6	45/10	DR2050R	**13**	15	37	86	NoD. TL on CUMA V2
05/16/00	8	45/10	DR2051A	**36**	14	**13**	87	6	45/10	DR2052R	**36**	14	**13**	87	NoD. TL on CUMA V2
05/17/00	8	45/10	DR2053A	**36**	**37**	**15**	86	6	45/10	DR2054R	**36**	**37**	**15**	86	NoD. TL on CUMA V2
05/18/00	8	45/10	DR2055A	14	**15**	**37**	91	6	45/10	DR2056R	14	**15**	**37**	91	NoD. TL on CUMA V2
05/23/00	8	54/7	DR2057A	**37**	36	**14**	86	6	54/7	DR2058R	**37**	36	**14**	86	NoD. TL on CUMA V2
05/24/00	8	54/7	DR2059A	**14**	**15**	**37**	87	6	54/7	DR2060R	**14**	**15**	**37**	87	NoD. TL on CUMA V2
05/25/00	8	54/7	DR2061A	36	101	**15**	86	6	54/7	DR2062R	36	101	**15**	86	NoD. TL on CUMA V2

Wet R - Red Diver. Wet Y - Yellow Diver. Stdby - Standby Diver. Numbers in diver columns are diver identification codes
BOLD Italics - dives not used in data analysis **Bold White** on grey - Team Leaders not on CUMA
Shading identifies divers who dived on consecutive days

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TABLE A2. DIVES CONDUCTED DURING SERIES 7-12 (cont'd)

Date	Series	Dive Prof	Ser No	Diver Identification				SI	Dive Prof	Ser No	Diver Identification				Comments
				Wet R	Wet Y	Stdby	TL				Wet R	Wet Y	Stdby	TL	
11/08/00	9	54/7	DR2080A	55	73	25	94	6	54/7	DR2081R	55	73	25	94	NoD TL on CUMA V2
11/09/00	9	54/7	DR2082A	38	39	19	95	6	54/7	DR2083R	38	39	19	95	NoD TL on CUMA V2
11/10/00	9	54/7	DR2084A	17	18	16	**93**	6	54/7	DR2085R	17	18	16	**97**	NoD TL diff 2nd dive
11/14/00	9	54/7	DR2087A	86	55	95	94	6	54/7	DR2088R	86	55	95	94	NoD TL on CUMA V2
11/15/00	9	60/6	DR2089A	25	38	39	93	6	60/6	DR2090R	25	38	39	93	NoD TL on CUMA V2
11/17/00	9	60/6	DR2093A	18	16	86	93	6	60/6	DR2094R	18	16	86	93	NoD TL on CUMA V2
11/27/00	9	45/10	DR2103A	39	19	17	93	6	45/10	DR2104R	39	19	17	93	NoD TL on CUMA V2
11/29/00	9	45/10	DR2107A	38	55	25	95	6	45/10	DR2108R	38	55	25	95	NoD TL on CUMA V2
11/30/00	9	45/10	DR2109A	17	39	19	93	6	45/10	DR2110R	17	16	19	93	NoD TL on CUMA V2 changed YD
03/06/01	10	***30/4***	***DR2143A***	***131***	***130***	***111***	***70***	6	60/6	DR2144R	110	130	111	70	NoD TL on CUMA V2 1st dive abort
03/07/01	10	60/6	DR2145A	110	112	56	95	6	60/6	DR2146R	110	112	56	95	NoD TL on CUMA V2
03/08/01	10	60/6	DR2147A	70	111	110	93	6	60/6	DR2148R	70	111	110	93	NoD TL on CUMA V2
11/15/01	11(pre)	48/9	DR2159A	71	95	97	93	6	48/9	DR2160R	71	95	97	93	NoD In-house pre-series TL on CUMA V2
11/23/01	11	72/5a	DR2168A	**133**	74	132	**71**	6	***8 &2 5***	***DR2169R***	***133***	***74***	***132***	**71**	WO2 2nd dive aborted 133 dived prev day
11/26/01	11	72/5a	DR2171A	**74**		**113**	**96**	6	72/5a	DR2172R	**74**	114	**113**	**96**	WO2 2nd dive new YD
11/27/01	11	72/5b	DR2173A	**74**	**113**	75	**97**	6	72/5b	DR2174R	**74**	**113**	75	**97**	WO2 reduce 9 msw stop
11/28/01	11	72/5b	DR2176A		44	114	**96**	6	72/5b	DR2177R	**133**	44	114	**96**	WO2 2nd dive new RD
11/29/01	11	51/8	DR2178A	132	133	75	71	6	51/8	DR2179R	132	**133**	75	71	NoD TL on CUMA V2
06/12/01	11	51/8	DR2180A	133	132	115	**96**	6	51/8	DR2181R	133	132	115	**71**	NoD New TL 2nd dive
10/12/01	11	72/5c	DR2182A	114	113	**115**	**96**	6	72/5c	DR2183R	114	113	**115**	**96**	3 min @ 9 msw switch He off
11/12/01	11	72/5d	DR2184A	44	**115**	**75**	**71**	6	72/5d	DR2185R	44	**115**	75	**71**	3 min @ 9 msw no gas switch
12/12/01	11	63/6	DR2186A	**74**	**75**	113	**97**	6	63/6	Cancelled					NoD DCS on 1st dive
12/13/01	11	63/5	DR2188A	**74**	115	114	**71**	6	63/5	DR2189R	74	115	114	**97**	NoD TL diff

Wet R - Red Diver Wet Y - Yellow Diver Stdby - Standby Diver Numbers in diver columns are diver identification codes

BOLD Italics - dives not used in data analysis **Bold White** on grey - Team Leaders not on CUMA

Shading identifies divers who dived on consecutive days

TABLE A2. DIVES CONDUCTED DURING SERIES 7-12 (cont'd)

Date	Series	Dive Prof	Ser No	Diver Identification				Sil	Dive Prof	Ser No	Diver Identification				Comments
				Wet R	Wet Y	Stdby	TI				Wet R	Wet Y	Stdby	TI	
01/17/02	12(B1)	36/14	DR2190A		71	97	94								NoD. In house pre series. TI on CUMA
01/23/02	12	48/9	DR2193A	**95**	134	77	**93**	6	48/9	DR2194R	**95**	134	77	**93**	NoD
01/24/02	12	42/11	DR2195A	135	**95**	57	**71**	6	42/11	DR2196R	135	**95**	57	**71**	NoD
01/25/02	12	42/11	DR2197A	77	134	76	**93**								NoD. no 2nd dive planned
01/28/02	12	36/14	DR2198A	57	134	135	**94**	6	36/14	DR2199R	57	134	135	**94**	NoD. TI on CUMA
01/29/02	12	75/6a	DR2200A	95	77	76	**71**	6	75/6a	DR2201R	95	77	76	**71**	IWO2
01/30/02	12	75/6a	DR2202A	**134**	57	135	**94**	6	75/6a	DR2203R	**134**	57	135	**94**	IWO2
01/31/02	12	75/6b	DR2204A	97	**134**	76	**95**	6	75/6b	DR2205R	97	**134**	76	**95**	IWO2
02/04/02	12	75/6b	DR2206A	134	**135**	57	**94**	6	75/6b	DR2207R	134	**135**	57	**94**	IWO2
02/05/02	12	72/5d	DR2208A	**77**	**135**	76	**93**	6	72/5d	DR2209R	**77**	**135**	76	**93**	3 min @ 9msw. no gas switch
02/06/02	12	72/6	DR2210A	**77**	134	57	**95**	6	72/6	DR2211R	**77**	134	57	**95**	IWO2
02/07/02	12	72/6	DR2212A	135	76	**95**	**94**	6	72/6	DR2213R	135	76	**95**	**94**	IWO2
02/11/02	12	18/55	DR2214A	57	**77**	135	**94**	6	36/14	DR2215R	57	**77**	135	97	NoD. TI diff on 2nd dive - on CUMA
02/12/02	12	75/6b	DR2216A	**98**	76	**77**	**94**	6	72/6	DR2217R	**98**	76	**77**	**94**	IWO2. 2nd dive 72 msw/6 min
02/13/02	12	18/55	DR2218A	76	**98**	**57**	**93**	6	36/14	DR2219R	76	**98**	**57**	83	NoD. TI diff on 2nd dive - on CUMA
02/14/02	12	30/20	DR2220A	135	77	**57**	94	6	30/18	DR2221R	135	77	**76**	94	NoD. TI on CUMA. New Stdby. 2nd dive
Total Subjects			**263**	**63**	**66**	**67**	**67**			**242**	**60**	**60**	**61**	**61**	
Total Valid Subjects - NOD				**48**	**51**	**51**	**33**				**46**	**46**	**47**	**34**	
Total Valid Subjects - IWO2				**13**	**13**	**14**					**13**	**13**	**13**		

Wet R - Red Diver Wet Y - Yellow Diver Stdby - Standby Diver Numbers in diver columns are diver identification codes
BOLD Italics - dives not used in data analysis **Bold White** on grey - Team Leaders not on CUMA
Shading identifies divers who dived on consecutive days

TABLE A3. TIME-WEIGHTED AVERAGE PO_2 FOR WET AND STANDBY DIVERS

Profile (msw/min)	Role	No. of divers		PO_2(max)	PO_2(min)	TWA PO_2 to end bottom time	TWA PO_2 to surface
18/55	W	4	Mean	1.54±0.04	0.98±0.06	1.31±0.07	1.31±0.07
			Min	1.49	0.91	1.24	1.24
			Max	1.58	1.05	1.38	1.38
	S	2	Mean	1.67±0.06	1.025±0.11	1.54±0.03	1.54±0.04
			Min	1.63	0.95	1.52	1.51
			Max	1.71	1.10	1.56	1.56
30/20	W	3	Mean	1.37±0.01	1.07±0.01	1.19±0.01	1.16±0.02
			Min	1.36	1.06	1.18	1.15
			Max	1.38	1.08	1.20	1.18
	S	2	Mean	1.58±0.02	1.16±0.08	1.38±0.01	1.35±0.01
			Min	1.56	1.10	1.37	1.34
			Max	1.59	1.21	1.38	1.35
36/14	W	10	Mean	1.55±0.17	1.10±0.10	1.21±0.11	1.18±0.10
			Min	1.38	1.02	1.14	1.11
			Max	1.90	1.35	1.50	1.45
	S	5	Mean	1.43±0.08	1.13±0.05	1.27±0.05	1.22±0.05
			Min	1.34	1.07	1.21	1.16
			Max	1.55	1.19	1.34	1.29
42/11	W	6	Mean	1.46±0.12	1.04±0.07	1.13±0.08	1.09±0.07
			Min	1.21	0.94	1.01	0.99
			Max	1.55	1.12	1.22	1.16
	S	3	Mean	1.53±0.15	1.05±0.06	1.26±0.05	1.19±0.03
			Min	1.38	0.99	1.21	1.16
			Max	1.67	1.11	1.30	1.22
45/10	W	28	Mean	1.68±0.14	1.0±0.10	1.19±0.07	1.12±0.06
			Min	1.44	0.83	1.04	0.98
			Max	1.98	1.22	1.30	1.21
	S	14	Mean	1.67±0.19	1.10±0.10	1.31±0.07	1.23±0.06
			Min	1.44	0.97	1.22	1.15
			Max	2.09	1.30	1.44	1.36
48/9	W	8	Mean	1.66±0.10	1.05±0.07	1.21±0.09	1.11±0.07
			Min	1.52	0.95	1.09	1.01
			Max	1.85	1.13	1.36	1.24
	S	4	Mean	1.59±0.21	1.15±0.08	1.31±0.10	1.23±0.08
			Min	1.39	1.06	1.21	1.15
			Max	1.79	1.25	1.40	1.31
51/8	W	8	Mean	1.69±0.16	1.11±0.08	1.28±0.08	1.19±0.07
			Min	1.46	1.01	1.16	1.10
			Max	1.91	1.24	1.40	1.28
	S	4	Mean	1.70±0.21	1.16±0.08	1.31±0.10	1.21±0.08
			Min	1.40	1.06	1.20	1.12
			Max	1.86	1.25	1.43	1.30
54/7	W	28	Mean	1.75±0.18	1.24±0.07	1.34±0.07	1.23±0.05
			Min	1.53	1.12	1.19	1.08
			Max	2.11	1.38	1.45	1.31
	S	13	Mean	1.83±0.13	1.26±0.12	1.36±0.05	1.23±0.05
			Min	1.63	1.10	1.27	1.13
			Max	2.01	1.58	1.46	1.31

TABLE A3. TIME-WEIGHTED AVERAGE PO2 FOR WET AND STANDBY DIVERS (cont'd)

Profile (msw/min)	Role	No. of divers		PO_2(max)	PO_2(min)	TWA PO_2 to end bottom time	TWA PO_2 to surface
60/5	W	35	Mean	1.92±0.18	1.21±0.07	1.35±0.10	1.19±0.07
			Min	1.43	1.09	1.11	1.01
			Max	2.25	1.34	1.53	1.32
	S	17	Mean	1.96±0.15	1.23±0.12	1.36±0.08	1.19±0.06
			Min	1.72	1.07	1.20	1.08
			Max	2.29	1.40	1.53	1.34
60/6	W	17	Mean	1.91±0.16	1.24±0.10	1.39±0.08	1.24±0.07
			Min	1.66	1.12	1.22	1.12
			Max	2.23	1.43	1.51	1.37
	S	9	Mean	1.94±0.13	1.31±0.10	1.41±0.08	1.25±0.06
			Min	1.82	1.14	1.29	1.17
			Max	2.16	1.43	1.51	1.33
63/5	W	6	Mean	1.84±0.12	1.23±0.08	1.32±0.07	1.20±0.06
			Min	1.64	1.14	1.23	1.12
			Max	1.98	1.35	1.42	1.27
	S	3	Mean	1.85±0.09	1.27±0.06	1.34±0.06	1.22±0.04
			Min	1.78	1.22	1.27	1.17
			Max	1.95	1.33	1.38	1.24
69/5	W	38	Mean	1.98±0.16	1.35±0.11	1.40±0.11	1.23±0.08
			Min	1.63	1.19	1.13	1.01
			Max	2.20	1.66	1.59	1.40
	S	20	Mean	1.98±0.15	1.42±0.14	1.40±0.08	1.23±0.06
			Min	1.70	1.18	1.24	1.11
			Max	2.31	1.68	1.56	1.33
72/5	W	24	Mean	1.86±0.15	1.40±0.11	1.33±0.13	
			Min	1.57	1.25	1.18	
			Max	2.22	1.59	1.60	
	S	13	Mean	2.02±0.18	1.38±0.13	1.45±0.13	
			Min	1.77	1.26	1.23	
			Max	2.37	1.75	1.74	
72/6	W	10	Mean	2.01±0.23	1.35±0.09	1.42±0.13	
			Min	1.77	1.21	1.29	
			Max	2.42	1.50	1.66	
	S	5	Mean	2.01±0.24	1.40±.0.06	1.43±0.10	
			Min	1.73	1.33	1.32	
			Max	2.31	1.46	1.54	
75/6	W	18	Mean	2.06±0.20	1.43±0.16	1.47±0.11	
			Min	1.69	1.14	1.24	
			Max	2.46	1.79	1.63	
	S	9	Mean	2.07±0.20	1.33±0.09	1.47±0.13	
			Min	1.78	1.14	1.29	
			Max	2.42	1.45	1.64	

TABLE A4. POST-DIVE DOPPLER RESULTS FOR PRIMARY NOD DIVES

Profile (msw/min)	Dive No.	Role	No. of Divers	Precordial - Rest					Precordial - Movement					All Sites - Maximum					DCS
				0	1	2	3	4	0	1	2	3	4	0	1	2	3	4	
45/10	1	W	15	8	1	2	4	0	5	3	1	6	0	4	3	2	6	0	0
		S	7	5	2	0	0	0	4	2	1	0	0	1	4	2	0	0	0
		L	7	5	1	0	1	0	3	1	2	1	0	3	0	3	1	0	0
	2	W	13	7	3	2	1	0	4	1	3	5	0	4	1	3	5	0	0
		S	7	4	1	2	0	0	2	2	1	2	0	2	2	1	2	0	0
		L	7	6	1	0	0	0	4	2	1	0	0	3	3	1	0	0	0
54/7	1	W	14	12	1	1	0	0	10	3	1	0	0	5	8	1	0	0	0
		S	7	6	1	0	0	0	5	1	1	0	0	1	5	1	0	0	0
		L	6	5	1	0	0	0	4	1	0	1	0	3	1	1	1	0	0
	2	W	14	11	2	1	0	0	10	3	1	0	0	6	5	3	0	0	0
		S	7	4	3	0	0	0	4	2	1	0	0	0	6	1	0	0	0
		L	6	4	2	0	0	0	4	1	0	1	0	4	0	1	1	0	0
60/5 Ser. 7(IH)	1	W	8	3	3	2	0	0	3	1	2	2	0	1	3	2	2	0	0
		S	4	3	0	0	1	0	3	0	0	1	0	3	0	0	1	0	0
	2	W	6	5	0	0	1	0	4	1	0	1	0	3	2	0	1	0	0
		S	3	3	0	0	0	0	3	0	0	0	0	2	1	0	0	0	0
60/5 Ser. 7	1	W	10	7	2	1	0	0	7	2	0	1	0	4	4	0	2	0	0
		S	5	5	0	0	0	0	4	1	0	0	0	4	1	0	0	0	0
		L	1	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	
	2	W	10	7	3	0	0	0	6	3	0	1	0	4	3	2	1	0	0
		S	6	6	0	0	0	0	6	0	0	0	0	4	2	0	0	0	0
		L	0																
60/6	1	W	9	9	0	0	0	0	6	3	0	0	0	4	3	1	1	0	0
		S	4	3	1	0	0	0	2	1	1	0	0	2	1	0	1	0	0
		L	4	3	0	0	1	0	3	0	0	1	0	2	1	0	1	0	0
	2	W	9	8	1	0	0	0	6	3	0	0	0	4	3	2	0	0	0
		S	5	5	0	0	0	0	4	1	0	0	0	1	3	1	0	0	0
		L	5	4	1	0	0	0	4	0	1	0	0	2	2	1	0	0	0
69/5	1	W	20	19	0	1	0	0	16	1	3	0	0	10	7	3	0	0	0
		S	11	10	0	1	0	0	9	1	1	0	0	4	4	3	0	0	0
		L	11	11	0	0	0	0	11	0	0	0	0	9	2	0	0	0	0
	2	W	18	16	1	1	0	0	15	2	1	0	0	11	4	2	1	0	0
		S	9	8	1	0	0	0	7	2	0	0	0	3	3	2	1	0	0
		L	8	8	0	0	0	0	8	0	0	0	0	5	3	0	0	0	0
Totals			276	221	32	14	9	0	187	44	22	23	0	119	90	39	28	0	0

TABLE A5. POST-DIVE DOPPLER SUMMARY FOR PRIMARY NOD DIVES

Profile (msw/min)	Dive No.	Role	No. of Man-dives	Precordial Rest		Prec. Move		All Sites Max.		DCS
				BG > 0	**BG > 2**	BG > 0	**BG > 2**	BG > 0	**BG > 2**	
45/10	1	W	15	7/15	**4/15**	10/15	**6/15**	11/15	**6/15**	0
		S	7	2/7	**0/7**	3/7	**0/7**	6/7	**0/7**	0
		L	7	2/7	**1/7**	4/7	**1/7**	4/7	**1/7**	0
	2	W	13	6/13	**1/13**	9/13	**5/13**	9/13	**5/13**	0
		S	7	3/7	**0/7**	5/7	**2/7**	5/7	**2/7**	0
		L	7	1/7	**0/7**	3/7	**0/7**	4/7	**0/7**	0
54/7	1	W	14	2/14	**0/14**	4/14	**0/14**	9/14	**0/14**	0
		S	7	1/7	**0/7**	2/7	**0/7**	6/7	**0/7**	0
		L	6	1/6	**0/6**	2/6	**1/6**	3/6	**1/6**	0
	2	W	14	3/14	**0/14**	4/14	**0/14**	8/14	**0/14**	0
		S	7	3/7	**0/7**	3/7	**0/7**	7/7	**0/7**	0
		L	6	2/6	**0/6**	2/6	**1/6**	2/6	**1/6**	0
60/5 Ser. 7(IH)	1	W	8	5/8	**0/8**	5/8	**2/8**	7/8	**2/8**	0
		S	4	1/4	**1/4**	1/4	**1/4**	1/4	**1/4**	0
	2	W	6	1/6	**1/6**	2/6	**1/6**	3/6	**1/6**	0
		S	3	0/3	**0/3**	0/3	**0/3**	1/3	**0/3**	0
60/5 Ser. 7	1	W	10	3/10	**0/10**	3/10	**1/10**	6/10	**2/10**	0
		S	5	0/5	**0/5**	1/5	**0/5**	1/5	**0/5**	0
		L	1	0/1	**0/1**	0/1	**0/1**	0/1	**0/1**	0
	2	W	10	3/10	**0/10**	4/10	**1/10**	6/10	**1/10**	0
		S	6	0/6	**0/6**	0/6	**0/6**	2/6	**0/6**	0
		L								
60/6	1	W	9	0/9	**0/9**	3/9	**0/9**	5/9	**1/9**	0
		S	4	1/4	**0/4**	2/4	**0/4**	2/4	**1/4**	0
		L	4	1/4	**1/4**	1/4	**1/4**	2/4	**1/4**	0
	2	W	9	1/9	**0/9**	3/9	**0/9**	5/9	**0/9**	0
		S	5	0/5	**0/5**	1/5	**0/5**	4/5	**0/5**	0
		L	5	1/5	**0/5**	1/5	**0/5**	3/5	**0/5**	0
69/5	1	W	20	1/20	**0/20**	4/20	**0/20**	10/20	**0/20**	0
		S	11	1/11	**0/11**	2/11	**0/11**	7/11	**0/11**	0
		L	11	0/11	**0/11**	0/11	**0/11**	2/11	**0/11**	0
	2	W	18	2/18	**0/18**	3/18	**0/18**	7/18	**1/18**	0
		S	9	1/9	**0/9**	2/9	**0/9**	6/9	**1/9**	0
		L	8	0/8	**0/8**	0/8	**0/8**	3/8	**0/8**	0

TABLE A6. POST-DIVE DOPPLER RESULTS FOR SECONDARY NOD DIVES

Profile msw/min	Dive No.	Role	No. of Divers	Precordial - Rest					Precordial - Movement					All Sites - Maximum					DCS
				0	1	2	3	4	0	1	2	3	4	0	1	2	3	4	
18/55	1	W	4	2	2	0	0	0	2	0	2	0	0	1	1	2	0	0	0
		S	2	2	0	0	0	0	2	0	0	0	0	2	0	0	0	0	0
36/14[1]	2	W	4	1	1	1	1	0	1	0	1	2	0	1	0	1	2	0	0
		S	2	2	0	0	0	0	1	1	0	0	0	1	1	0	0	0	0
		L	0	Team leaders were new divers on CUMA, included below as first dives															
30/20[2]	1	W	2	0	0	1	1	0	0	0	0	2	0	0	0	0	2	0	0
		S	2	2	0	0	0	0	1	1	0	0	0	1	1	0	0	0	0
		L	1	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0
30/18	2	W	2	0	0	2	0	0	0	0	0	2	0	0	0	0	2	0	0
		S	0	New Standby diver, results put in with 30/20 first dive Standby															
		L	1	1	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0
36/14	1	W	3	3	0	0	0	0	3	0	0	0	0	1	2	0	0	0	0
		S	2	2	0	0	0	0	2	0	0	0	0	1	0	1	0	0	0
		L	4	4	0	0	0	0	4	0	0	0	0	3	1	0	0	0	0
	2	W	2	2	0	0	0	0	2	0	0	0	0	2	0	0	0	0	0
		S	1	1	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0
		L	1	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0
42/11	1	W	4	3	0	0	1	0	2	0	1	1	0	1	1	1	1	0	0
		S	2	2	0	0	0	0	2	0	0	0	0	1	0	0	1	0	0
	2	W	2	1	0	1	0	0	0	1	1	0	0	0	1	1	0	0	0
		S	1	1	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0
48/9	1	W	4	3	1	0	0	0	3	0	1	0	0	1	1	2	0	0	0
		S	2	2	0	0	0	0	1	1	0	0	0	1	1	0	0	0	0
		L	1	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0
	2	W	4	4	0	0	0	0	3	1	0	0	0	2	2	0	0	0	0
		S	2	1	1	0	0	0	1	1	0	0	0	0	2	0	0	0	0
		L	1	1	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0
51/8	1	W	4	2	0	0	2	0	2	0	0	2	0	2	0	0	1	1	0
		S	2	2	0	0	0	0	2	0	0	0	0	1	1	0	0	0	0
		L	1	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0
	2	W	4	2	0	1	1	0	2	0	0	2	0	2	0	0	2	0	0
		S	2	2	0	0	0	0	2	0	0	0	0	1	1	0	0	0	0
		L	1	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0
63/5	1	W	2	2	0	0	0	0	2	0	0	0	0	1	1	0	0	0	0
		S	1	1	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0
	2	W	2	2	0	0	0	0	2	0	0	0	0	2	0	0	0	0	0
		S	1	1	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0
63/6[3]	1	W	2	2	0	0	0	0	2	0	0	0	0	0	2	0	0	0	0
		S	1	0	0	1	0	0	0	0	0	1	0	0	0	0	1	0	1
Totals			79	61	5	7	6	0	54	7	6	12	0	33	23	9	13	1	1

1. Team Leaders did not do the first dive, hence their data are included below as 36 msw/14 min first dive.
2. Includes Standby diver from second dive (30 msw/18 min) who did not do the first dive.
3. Only one dive done, as Standby diver reported symptoms of CNS DCS after first Doppler reading and was treated. Only one Doppler reading was taken on the Wet divers as they were also recompressed to 18 msw for one O2 cycle. Hence peak Bubble Scores may not have been attained.

TABLE A7. POST-DIVE DOPPLER SUMMARY FOR SECONDARY NOD DIVES

Profile (msw/min)	Dive No.	Role	No. man dives	Precordial Rest		Prec. Move		All Sites Max.		DCS
				BG > 0	BG > 2	BG > 0	BG > 2	BG > 0	BG > 2	
18/55	1	W	4	2/4	0/4	2/4	0/4	3/4	0/4	0
		S	2	0/2	0/2	0/2	0/2	0/2	0/2	0
36/14	2	W	4	3/4	1/4	3/4	2/4	3/4	2/4	0
		S	2	0/2	0/2	1/2	0/2	1/2	0/2	0
30/20	1	W	2	2/2	1/2	2/2	2/2	2/2	2/2	0
		S	2[a]	0/2	0/2	1/2	0/2	1/2	0/2	0
		L	1	0/1	0/1	0/1	0/1	0/1	0/1	0
30/18	2	W	2	2/2	0/2	2/2	2/2	2/2	2/2	0
		L	1	0/1	0/1	1/1	0/1	1/1	0/1	0
36/14	1	W	3	0/3	0/3	0/3	0/3	2/3	0/3	0
		S	2	0/2	0/2	0/2	0/2	1/2	0/2	0
		L	4[b]	0/4	0/4	0/4	0/4	1/4	0/4	0
	2	W	2	0/2	0/2	0/2	0/2	0/2	0/2	0
		S	1	0/1	0/1	0/1	0/1	1/1	0/1	0
		L	1	0/1	0/1	0/1	0/1	0/1	0/1	0
42/11	1	W	4	1/4	1/4	2/4	1/4	3/4	1/4	0
		S	2	0/2	0/2	0/2	0/2	1/2	1/2	0
	2	W	2	1/2	0/2	2/2	0/2	2/2	0/2	0
		S	1	0/1	0/1	0/1	0/1	1/1	0/1	0
48/9	1	W	4	1/4	0/4	1/4	0/4	3/4	0/4	0
		S	2	0/2	0/2	1/2	0/2	1/2	0/2	0
		L	1	0/1	0/1	0/1	0/1	0/1	0/1	0
	2	W	4	0/4	0/4	1/4	0/4	2/4	0/4	0
		S	2	1/2	0/2	1/2	0/2	2/2	0/2	0
		L	1	0/1	0/1	0/1	0/1	1/1	0/1	0
51/8	1	W	4	2/4	2/4	2/4	2/4	2/4	2/4	0
		S	2	0/2	0/2	0/2	0/2	1/2	0/2	0
		L	1	0/1	0/1	0/1	0/1	0/1	0/1	0
	2	W	4	2/4	1/4	2/4	2/4	2/4	2/4	0
		S	2	0/2	0/2	0/2	0/2	1/2	0/2	0
		L	1	0/1	0/1	0/1	0/1	0/1	0/1	0
63/5	1	W	2	0/2	0/2	0/2	0/2	1/2	0/2	0
		S	1	0/1	0/1	0/1	0/1	1/1	0/1	0
	2	W	2	0/2	0/2	0/2	0/2	0/2	0/2	0
		S	1	0/1	0/1	0/1	0/1	1/1	1/1	0
63/6	1[c]	W	2	0/2	0/2	0/2	0/2	2/2	0/2	0
		S	1	1/1	0/1	1/1	1/1	1/1	1/1	1

a. Includes Standby Diver from second dive (30/18) who did not do the first dive

b. Includes the 2 Team Leaders from the 18/55 + 36/14 combination

c. Second dive not conducted because of DCS (Standby) and subsequent treatment

TABLE A8. POST-DIVE DOPPLER RESULTS FOR DEEP, SHORT-DECOMPRESSION DIVES

Profile msw/min	Dive No.	Role	No. of Divers	Precordial - Rest					Precordial - Movement					All Sites - Maximum					DCS
				0	1	2	3	4	0	1	2	3	4	0	1	2	3	4	
72/5a	1	W	4	4	0	0	0	0	4	0	0	0	0	3	1	0	0	0	0
		S	2	2	0	0	0	0	1	1	0	0	0	1	0	0	1	0	0
	2	W	1	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0
		S	1	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0
72/5b	1	W	4	4	0	0	0	0	4	0	0	0	0	3	1	0	0	0	0
		S	2	2	0	0	0	0	2	0	0	0	0	0	2	0	0	0	0
	2	W	3	3	0	0	0	0	3	0	0	0	0	1	2	0	0	0	0
		S	2	2	0	0	0	0	2	0	0	0	0	1	0	1	0	0	0
72/5c	1	W	2	2	0	0	0	0	2	0	0	0	0	0	2	0	0	0	0
		S	1	1	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0
	2	W	2	1	1	0	0	0	1	1	0	0	0	0	2	0	0	0	0
		S	1	1	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0
72/5d	1	W	4	4	0	0	0	0	3	1	0	0	0	2	2	0	0	0	0
		S	2	2	0	0	0	0	2	0	0	0	0	0	2	0	0	0	0
	2	W	4	4	0	0	0	0	3	1	0	0	0	0	3	1	0	0	0
		S	2	1	1	0	0	0	1	0	1	0	0	1	0	1	0	0	0
72/6	1	W	4	4	0	0	0	0	4	0	0	0	0	2	1	1	0	0	0
		S	2	2	0	0	0	0	2	0	0	0	0	1	1	0	0	0	0
	2	W	4	4	0	0	0	0	4	0	0	0	0	3	1	0	0	0	0
		S	2	2	0	0	0	0	1	1	0	0	0	0	2	0	0	0	0
75/6a	1	W	4	4	0	0	0	0	4	0	0	0	0	4	0	0	0	0	0
		S	2	2	0	0	0	0	2	0	0	0	0	0	0	2	0	0	0
	2	W	4	4	0	0	0	0	4	0	0	0	0	3	1	0	0	0	0
		S	2	2	0	0	0	0	2	0	0	0	0	2	0	0	0	0	0
75/6b	1	W	4	4	0	0	0	0	3	1	0	0	0	3	1	0	0	0	0
		S	2	1	1	0	0	0	2	0	0	0	0	0	1	1	0	0	0
	2	W	4	4	0	0	0	0	4	0	0	0	0	4	0	0	0	0	0
		S	2	2	0	0	0	0	2	0	0	0	0	1	1	0	0	0	0
75/6b	1	W	2	2	0	0	0	0	2	0	0	0	0	2	0	0	0	0	0
		S	1	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0
72/6	2	W	2	2	0	0	0	0	2	0	0	0	0	2	0	0	0	0	0
		S	1	0	1	0	0	0	0	0	0	1	0	0	0	0	1	0	0
Totals			**79**	75	4	0	0	0	71	6	1	1	0	42	28	7	2	0	0

Annex B: CUMA Decompression Tables

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TABLE B1. CF TABLE 10 (METRES): CUMA - NO-DECOMPRESSION (VERSION 2)

Depth (msw)	Bottom Time (min)	In-Water Stop Times (min) at Different Depths (msw)								Decom. Time (min)
		HeO_2							O_2	
		30	27	24	21	18	15	12	9	
12	120	-	-	-	-	-	-	-	-	1
15	75	-	-	-	-	-	-	-	-	1
18	55	-	-	-	-	-	-	-	-	1
21	40	-	-	-	-	-	-	-	-	2
24	30	-	-	-	-	-	-	-	-	2
27	23	-	-	-	-	-	-	-	-	2
30	18	-	-	-	-	-	-	-	-	2
33	16	-	-	-	-	-	-	-	-	2
36	14	-	-	-	-	-	-	-	-	2
39	12	-	-	-	-	-	-	-	-	3
42	11	-	-	-	-	-	-	-	-	3
45	10	-	-	-	-	-	-	-	-	3
48	9	-	-	-	-	-	-	-	-	3
51	8	-	-	-	-	-	-	-	-	3
54	7	-	-	-	-	-	-	-	-	3
57	6	-	-	-	-	-	-	-	-	4
60	6	-	-	-	-	-	-	-	-	4
63	5	-	-	-	-	-	-	-	-	4
66	5	-	-	-	-	-	-	-	-	4
69	5	-	-	-	-	-	-	-	-	4

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TABLE B2. CF TABLES 10-12 (VERSION 2)

Depth (msw)	Bottom Time (min)	Stop Times (min) at Different Depths (msw)[1]									
		In-Water Stops HeO_2									
		39	36	33	30	27	24	21	18	15	12
12	120	-	-	-	-	-	-	-	-	-	-
15	75	-	-	-	-	-	-	-	-	-	-
18	55	-	-	-	-	-	-	-	-	-	-
21	40	-	-	-	-	-	-	-	-	-	-
24	30	-	-	-	-	-	-	-	-	-	-
27	23	-	-	-	-	-	-	-	-	-	-
30	18	-	-	-	-	-	-	-	-	-	-
	25	-	-	-	-	-	-	-	-	-	4
	30	-	-	-	-	-	-	-	-	-	4
	35	-	-	-	-	-	-	-	-	-	4
	40	-	-	-	-	-	-	-	-	-	4
	45	-	-	-	-	-	-	-	-	-	*4*
	50	-	-	-	-	-	-	-	-	-	*4*
	55	-	-	-	-	-	-	-	-	-	*4*
	60	-	-	-	-	-	-	-	-	-	*4*
	65	-	-	-	-	-	-	-	-	-	*4*
33	16	-	-	-	-	-	-	-	-	-	-
	20	-	-	-	-	-	-	-	-	-	4
	25	-	-	-	-	-	-	-	-	-	4
	30	-	-	-	-	-	-	-	-	-	4
	35	-	-	-	-	-	-	-	-	-	4
	40	-	-	-	-	-	-	-	-	-	4
	45	-	-	-	-	-	-	-	-	-	*4*
	50	-	-	-	-	-	-	-	-	-	5
	55	-	-	-	-	-	-	-	-	-	5
	60	-	-	-	-	-	-	-	-	*3*	*6*
36	14	-	-	-	-	-	-	-	-	-	-
	20	-	-	-	-	-	-	-	-	-	4
	25	-	-	-	-	-	-	-	-	-	4
	30	-	-	-	-	-	-	-	-	-	5
	35	-	-	-	-	-	-	-	-	3	3
	40	-	-	-	-	-	-	-	-	*3*	*3*
	45	-	-	-	-	-	-	-	-	*3*	*4*
	50	-	-	-	-	-	-	-	-	*4*	*7*

In-Water Deco.	
fWO_2	Total Dec Time (min)
9	
-	1
-	1
-	1
-	2
-	2
-	2
-	2
21	*26*
26	*31*
30	*35*
34	*39*
39	*44*
43	*48*
50	*55*
58	*63*
64	*69*
-	2
20	*25*
25	*30*
31	*36*
36	*41*
41	*46*
46	*51*
55	*61*
64	*70*
72	*82*
-	2
24	*29*
30	*35*
35	*41*
42	*49*
48	*55*
59	*67*
68	*80*

Surface Decompression			
fWO_2	Surf Int. (min)[2]	RCC^3 O_2	Total Dec. Time (min)
9		*12*	
-		-	1
-		-	1
-		-	1
-		-	2
-		-	2
-		-	2
-		-	2
5	7	*18*	*35*
5		*22*	*39*
5		*27*	*44*
5		*30**	*52*
5		*35**	*57*
6		*42**	*65*
8		*48**	*73*
10		*53**	*80*
12		*57**	*88*
-	7	-	2
5		*18*	*33*
5		*22*	*39*
5		*27*	*44*
5		*30**	*52*
6		*37**	*60*
9		*43**	*69*
11		*50**	*79*
13		*56**	*87*
13		*60***	*100*
-	7	-	2
5		*20*	*37*
5		*26*	*43*
5		*30**	*53*
7		*37**	*63*
10		*44**	*73*
12		*52**	*84*
12		*60**	*98*

1. Stop times include travel time from the previous stop except when a gas switch occurs.
2. Time from leaving the 9 msw stop to reaching the 12 msw chamber stop must not exceed 7 min
3. Asterisk (*) indicates number of 5 min air breaks required.

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TABLE B2. CF TABLES 10-12 (VERSION 2) (cont'd)

Depth (msw)	Bottom Time (min)	Stop Times (min) at Different Depths (msw)[1]										In-Water Deco.		Surface Decompression			
		In-Water Stops HeO_2										IWO_2	Total Dec. Time (min)	IWO_2	Surf.Int. (msw)[2]	RCC[3] O_2	Total Dec. Time (min)
		39	36	33	30	27	24	21	18	15	12	9		9		12	
39	12	-	-	-	-	-	-	-	-	-	-	-	3	-	7	-	3
	15	-	-	-	-	-	-	-	-	-	4	20	25	5		18	33
	20	-	-	-	-	-	-	-	-	-	4	27	32	5		23	40
	25	-	-	-	-	-	-	-	-	3	3	34	41	5		30*	54
	30	-	-	-	-	-	-	-	-	3	4	40	48	7		35*	62
	35	-	-	-	-	-	-	-	-	4	4	48	57	10		43*	74
	40	-	-	-	-	-	-	-	-	5	4	60	70	12		53*	87
	45	-	-	-	-	-	-	-	3	3	8	70	85	12		60**	104
	50	-	-	-	-	-	-	-	3	3	12	77	96	12		63**	111
42	11	-	-	-	-	-	-	-	-	-	-	-	3	-	7	-	3
	15	-	-	-	-	-	-	-	-	-	4	23	28	5		18	35
	20	-	-	-	-	-	-	-	-	3	3	30	37	5		27	46
	25	-	-	-	-	-	-	-	-	4	4	38	47	5		33*	59
	30	-	-	-	-	-	-	-	3	2	4	46	56	9		42*	73
	35	-	-	-	-	-	-	-	3	3	5	58	70	12		51*	87
	40	-	-	-	-	-	-	-	4	3	9	69	86	12		60**	106
	45	-	-	-	-	-	-	-	4	4	12	78	99	12		64**	114
45	10	-	-	-	-	-	-	-	-	-	-	-	3	-	7	-	3
	15	-	-	-	-	-	-	-	-	3	2	25	31	5		21	39
	20	-	-	-	-	-	-	-	-	4	4	33	42	5		30	51
	25	-	-	-	-	-	-	-	3	3	4	43	54	8		37*	68
	30	-	-	-	-	-	-	-	4	3	4	53	65	11		48*	83
	35	-	-	-	-	-	-	3	2	4	8	67	85	12		59*	101
	40	-	-	-	-	-	-	3	3	4	12	77	100	12		64**	116
	45	-	-	-	-	-	-	3	4	7	12	88	113	14		70**	128
48	9	-	-	-	-	-	-	-	-	-	-	-	3	-	7	-	3
	10	-	-	-	-	-	-	-	-	-	5	17	23	5		13	31
	15	-	-	-	-	-	-	-	-	4	3	28	36	5		24	44
	20	-	-	-	-	-	-	-	3	3	3	37	47	6		30*	58
	25	-	-	-	-	-	-	3	2	3	4	47	60	10		42*	77
	30	-	-	-	-	-	-	3	3	3	8	61	79	11		58*	97
	35	-	-	-	-	-	-	4	3	4	11	74	97	12		61**	113
	40	-	-	-	-	-	3	2	3	7	12	85	113	14		69**	128

1. Stop times include travel time from the previous stop except when a gas switch occurs.
2. Time from leaving the 9 msw stop to reaching the 12 msw chamber stop must not exceed 7 min
3. Asterisk (*) indicates number of 5 min air breaks required.

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TABLE B2. CF TABLES 10-12 (VERSION 2) (cont'd)

Depth (msw)	Bottom Time (min)	Stop Times (min) at Different Depths (msw)[1]										In-Water Deco.		Surface Decompression			
		In-Water Stops HeO_2										IWO_2	Total Dec. Time (min)	IWO_2	Surf.Int. (min)[2]	RCC[3] O_2	Total Dec. Time (min)
		39	36	33	30	27	24	21	18	15	12	9		9		12	
51	8	-	-	-	-	-	-	-	-	-	-	-	3	-	7	-	3
	10	-	-	-	-	-	-	-	-	-	5	19	25	5		15	33
	15	-	-	-	-	-	-	-	3	2	3	31	40	5		27	48
	20	-	-	-	-	-	-	-	5	3	3	41	53	8		34*	66
	25	-	-	-	-	-	-	*4*	*2*	*4*	*5*	*54*	*70*	11		49*	88
	30	-	-	-	-	-	*3*	*2*	*3*	*4*	*9*	*70*	*92*	*12*		*60***	*111*
	35	-	-	-	-	-	*3*	*3*	*3*	*6*	*12*	*82*	*110*	*13*		*67***	*125*
	40	-	-	-	-	-	*4*	*3*	*3*	*10*	*13*	*91*	*125*	*15*		*74***	*140*
54	7	-	-	-	-	-	-	-	-	-	-	-	3	-	7	-	3
	10	-	-	-	-	-	-	-	-	4	2	22	29	5		17	36
	15	-	-	-	-	-	-	-	4	2	4	33	44	5		30	53
	20	-	-	-	-	-	-	4	2	3	4	45	59	9		39*	74
	25	-	-	-	-	-	*3*	*2*	*3*	*4*	*7*	*61*	*81*	11		58*	99
	30	-	-	-	-	-	*4*	*3*	*3*	*5*	*11*	*77*	*104*	*12*		*64***	*120*
	35	-	-	-	-	*3*	*2*	*3*	*3*	*9*	*13*	*88*	*122*	*14*		*72***	*137*
57	6	-	-	-	-	-	-	-	-	-	-	-	4	-	7	-	4
	10	-	-	-	-	-	-	-	-	4	3	23	31	5		19	39
	15	-	-	-	-	-	-	3	2	3	3	36	48	5		30*	59
	20	-	-	-	-	-	3	2	3	3	4	49	65	10		45*	83
	25	-	-	-	-	-	*4*	*3*	*3*	*3*	*10*	*69*	*93*	11		60***	112
	30	-	-	-	-	*3*	*2*	*3*	*4*	*7*	*11*	*84*	*115*	*14*		*68***	*130*
	35	-	-	-	-	*4*	*3*	*3*	*4*	*11*	*14*	*94*	*134*	*16*		*76***	*149*
60	6	-	-	-	-	-	-	-	-	-	-	-	4	-	7	-	4
	10	-	-	-	-	-	-	-	-	5	3	25	34	5		21	42
	15	-	-	-	-	-	-	4	2	3	3	39	52	7		31*	63
	20	-	-	-	-	-	*4*	*2*	*3*	*3*	*6*	*55*	*74*	11		50*	92
	25	-	-	-	-	*3*	*3*	*2*	*4*	*6*	*11*	*75*	*103*	*12*		*62***	*119*
	30	-	-	-	*3*	*2*	*2*	*3*	*4*	*9*	*13*	*89*	*126*	*15*		*72***	*141*
63	5	-	-	-	-	-	-	-	-	-	-	-	4	-	7	-	4
	6	-	-	-	-	-	-	-	-	-	4	4	9	4		-	9
	10	-	-	-	-	-	-	-	4	2	3	27	37	5		24	46
	15	-	-	-	-	-	4	2	2	3	3	42	57	8		37*	72
	20	-	-	-	-	*3*	*2*	*3*	*3*	*3*	*8*	*62*	*85*	11		58*	102
	25	-	-	-	*3*	*2*	*2*	*3*	*3*	*7*	*11*	*82*	*114*	*13*		*67***	*129*
	30	-	-	-	*4*	*2*	*3*	*3*	*5*	*10*	*14*	*94*	*136*	*16*		*76***	*151*

1. Stop times include travel time from the previous stop except when a gas switch occurs.
2. Time from leaving the 9 msw stop to reaching the 12 msw chamber stop must not exceed 7 min.
3. Asterisk (*) indicates number of 5 min air breaks required.

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TABLE B2. CF TABLES 10-12 (VERSION 2) (cont'd)

Depth (msw)	Bottom Time (min)	Stop Times (min) at Different Depths (msw)[1]									
		In-Water Stops HeO_2									
		39	36	33	30	27	24	21	18	15	12
66	5	-	-	-	-	-	-	-	-	-	-
	6	-	-	-	-	-	-	-	-	-	4
	10	-	-	-	-	-	-	-	5	2	3
	15	-	-	-	-	-	4	2	3	3	3
	20	-	-	-	-	4	2	3	3	3	10
	25	-	-	-	4	2	3	3	2	9	12
	30	-	-	3	2	3	2	3	8	10	16
69	5	-	-	-	-	-	-	-	-	-	-
	6	-	-	-	-	-	-	-	-	-	4
	10	-	-	-	-	-	-	4	2	2	4
	15	-	-	-	-	4	2	2	2	3	5
	20	-	-	-	4	2	2	3	2	5	11
	25	-	-	3	2	2	3	3	4	10	13
	30	-	3	2	2	2	3	3	9	12	18
72	6	-	-	-	-	-	-	-	-	-	4
	10	-	-	-	-	-	-	4	2	3	3
	15	-	-	-	-	4	2	2	3	3	6
	20	-	-	4	2	2	2	3	2	7	11
	25	-	3	2	2	2	3	2	7	10	15
75	6	-	-	-	-	-	-	-	-	-	4
	10	-	-	-	-	-	-	5	2	3	3
	15	-	-	-	4	2	2	2	3	3	8
	20	-	-	4	2	2	2	3	3	8	12
	25	-	4	2	2	2	3	3	8	11	17
78	6	-	-	-	-	-	-	-	-	5	3
	10	-	-	-	-	-	5	2	2	3	3
	15	-	-	-	4	2	2	3	2	3	9
	20	-	4	2	2	2	2	3	4	9	13
	25	4	2	2	2	2	3	4	9	12	19
81	6	-	-	-	-	-	-	-	-	6	2
	10	-	-	-	-	-	5	2	2	3	3
	15	-	-	4	2	2	2	2	3	4	10
	20	-	4	2	2	2	3	3	5	10	13
	25	4	2	2	2	3	3	5	10	13	21

In-Water Deco.	
IWO_2	Total Dec. Time (min)
9	
-	4
4	9
29	40
45	61
68	94
87	123
99	147
-	4
4	9
31	44
49	68
74	104
92	133
102	157
4	9
33	46
52	73
81	115
96	143
6	11
35	49
59	84
85	122
99	152
21	30
37	53
63	89
90	132
103	163
22	31
39	55
70	100
94	139
104	170

Surface Decompression			
IWO_2	Surf.Int. (min)[2]	RCC^3 O_2 12	Total Dec. Time (min)
9			
-	7	-	4
4		-	9
5		26	49
9		40*	77
11		60**	114
14		71**	138
20		76**	161
-	7	-	4
4		-	9
5		27	52
10		44*	85
12		61**	120
15		75**	148
25		74**	171
4	7	-	9
5		29	54
10		48*	91
13		66**	130
17		77**	158
6	7	-	11
5		30*	61
10		55*	102
14		69**	137
21		76**	167
6	7	30	52
6		30*	64
11		57*	106
15		73**	147
26		74**	177
7	7	30	53
7		32*	67
11		60**	118
18		75**	153
28		74**	185

1. Stop times include travel time from the previous stop except when a gas switch occurs.
2. Time from leaving the 9 msw stop to reaching the 12 msw chamber stop must not exceed 7 min
3. Asterisk (*) indicates number of 5 min air breaks required.

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TABLE B2. CF TABLES 10-12 (VERSION 2) (cont'd)

Depth (msw)	Bottom Time (min)	Stop Times (min) at Different Depths (msw)[1]										
		In-Water Stops HeO_2										
		42	39	36	33	30	27	24	21	18	15	12
84°	10	-	-	-	-	-	5	2	2	2	2	3
	15	-	-	-	4	2	2	2	3	3	5	10
	20	-	4	2	2	2	2	2	3	7	10	16
87°	10	-	-	-	-	-	5	2	2	2	3	3
	15	-	-	4	2	2	2	2	2	3	7	11
	20	4	2	2	2	2	2	2	4	8	12	17
90°	10	-	-	-	-	-	5	2	2	3	3	3
	15	-	-	5	2	2	2	2	3	3	8	11
	20	4	2	2	2	2	2	3	4	9	12	19

In-Water Deco.	
IWO_2	Total Dec. Time (min)
9	
42	59
74	106
97	148
44	62
79	115
101	159
46	65
84	123
102	164

Surface Decompression			
IWO_2	Surf.Int. (min)[2]	RCC^3 O_2	Total Dec. Time (min)
9		12	
9		35*	73
12		61**	122
18		77**	163
9		38*	77
13		65**	131
23		76**	174
10		40*	81
14		68**	138
25		75**	179

1. Stop times include travel time from the previous stop except when a gas switch occurs.
2. Time from leaving the 9 msw stop to reaching the 12 msw chamber stop must not exceed 7 min
3. Asterisk (*) indicates number of 5 min air breaks required.

a. Untested - Not in Canadian Forces Table 12 for CUMA Surface Decompression with Oxygen

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TABLE B3. CF TABLE 14 (METRES): CUMA REPETITIVE DIVE TABLE FOR SURFACE INTERVALS FROM 3 TO 6 HOURS (VERSION 2)

Depth (msw)	Bottom Time (min)	Stop Times (min) at Different Depths (msw)[1]													Total Dec Time (min)
		In-Water Stops											Surf. Int. (min)[2]	RCC[3]	
		HeO_2										O_2		O_2	
		39	36	33	30	27	24	21	18	15	12	9		12	
30	14	-	-	-	-	-	-	-	-	-	-	-	7	-	2
	20	-	-	-	-	-	-	-	-	-	4	5		19	36
	25	-	-	-	-	-	-	-	-	-	4	5		23	40
	30	-	-	-	-	-	-	-	-	-	4	5		28	45
	35	-	-	-	-	-	-	-	-	-	4	5		30*	52
	40	-	-	-	-	-	-	-	-	-	4	5		37*	59
	45	-	-	-	-	-	-	-	-	-	4	6		43*	66
	50	-	-	-	-	-	-	-	-	-	4	9		48*	74
	55	-	-	-	-	-	-	-	-	-	4	11		55*	83
33	12	-	-	-	-	-	-	-	-	-	-	-	7	-	2
	15	-	-	-	-	-	-	-	-	-	4	5		15	32
	20	-	-	-	-	-	-	-	-	-	4	5		21	38
	25	-	-	-	-	-	-	-	-	-	4	5		28	45
	30	-	-	-	-	-	-	-	-	-	4	5		30*	52
	35	-	-	-	-	-	-	-	-	-	4	6		37*	60
	40	-	-	-	-	-	-	-	-	-	4	9		43*	69
	45	-	-	-	-	-	-	-	-	-	5	10		49*	77
	50	-	-	-	-	-	-	-	-	3	3	13		57*	89
	55	-	-	-	-	-	-	-	-	3	5	13		60**	99
36	11	-	-	-	-	-	-	-	-	-	-	-	7	-	2
	15	-	-	-	-	-	-	-	-	-	4	5		18	35
	20	-	-	-	-	-	-	-	-	-	4	5		25	42
	25	-	-	-	-	-	-	-	-	-	4	5		30*	52
	30	-	-	-	-	-	-	-	-	3	3	6		36*	61
	35	-	-	-	-	-	-	-	-	3	3	9		43*	71
	40	-	-	-	-	-	-	-	-	3	4	11		51*	82
	45	-	-	-	-	-	-	-	-	4	7	12		60*	96

1. Stop times include travel time from the previous stop except when a gas switch occurs.
2. Time from leaving the 9 msw stop to reaching the 12 msw chamber stop must not exceed 7 min
3. Asterisk (*) indicates number of 5 min air breaks required.

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TABLE B3. CF TABLE 14 (METRES): CUMA REPETITIVE DIVE TABLE FOR SURFACE INTERVALS FROM 3 TO 6 HOURS (VERSION 2) (cont'd)

Depth (msw)	Bottom Time (min)	Stop Times (min) at Different Depths (msw)[1]													Total Dec Time (min)
		In-Water Stops											Surf. Int. (min)[2]	RCC[3]	
		HeO_2										O_2		O_2	
		39	36	33	30	27	24	21	18	15	12	9		12	
39	9	-	-	-	-	-	-	-	-	-	-	-	7	-	3
	15	-	-	-	-	-	-	-	-	-	4	5		22	39
	20	-	-	-	-	-	-	-	-	3	2	5		29	47
	25	-	-	-	-	-	-	-	-	3	4	7		35*	62
	30	-	-	-	-	-	-	-	-	4	4	9		42*	72
	35	-	-	-	-	-	-	-	-	5	4	12		51*	85
	40	-	-	-	-	-	-	-	3	3	8	12		60*	99
	45	-	-	-	-	-	-	-	3	4	13	13		66**	117
42	8	-	-	-	-	-	-	-	-	-	-	-	7	-	3
	10	-	-	-	-	-	-	-	-	-	4	5		15	32
	15	-	-	-	-	-	-	-	-	3	2	5		24	42
	20	-	-	-	-	-	-	-	-	4	3	5		30*	55
	25	-	-	-	-	-	-	-	3	2	4	8		38*	68
	30	-	-	-	-	-	-	-	3	3	4	11		48*	82
	35	-	-	-	-	-	-	-	4	3	8	11		58*	97
	40	-	-	-	-	-	-	-	5	3	13	13		66**	118
45	8	-	-	-	-	-	-	-	-	-	-	-	7	-	3
	10	-	-	-	-	-	-	-	-	-	4	5		17	34
	15	-	-	-	-	-	-	-	-	4	3	5		27	47
	20	-	-	-	-	-	-	-	3	2	4	6		33*	61
	25	-	-	-	-	-	-	-	4	3	4	11		45*	80
	30	-	-	-	-	-	-	3	2	3	7	11		56*	95
	35	-	-	-	-	-	-	3	3	4	11	12		62**	113
	40	-	-	-	-	-	-	3	4	7	12	14		70**	128
48	7	-	-	-	-	-	-	-	-	-	-	-	7	-	3
	10	-	-	-	-	-	-	-	-	3	3	5		20	39
	15	-	-	-	-	-	-	-	3	2	3	5		30	51
	20	-	-	-	-	-	-	-	4	3	4	8		38*	70
	25	-	-	-	-	-	-	3	3	3	6	10		51*	89
	30	-	-	-	-	-	-	4	3	3	10	12		60**	110
	35	-	-	-	-	-	3	2	3	7	12	14		69**	128

1. Stop times include travel time from the previous stop except when a gas switch occurs.
2. Time from leaving the 9 msw stop to reaching the 12 msw chamber stop must not exceed 7 min
3. Asterisk (*) indicates number of 5 min air breaks required.

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TABLE B2. CF TABLE 14 (METRES): CUMA REPETITIVE DIVE TABLE FOR SURFACE INTERVALS FROM 3 TO 6 HOURS (VERSION 2) (cont'd)

Depth (msw)	Bottom Time (min)	Stop Times (min) at Different Depths (msw)[1]											Surf. Int. (min)[2]	RCC[3]	Total Dec Time (min)
		In-Water Stops													
		HeO_2										O_2		O_2	
		39	36	33	30	27	24	21	18	15	12	9		12	
51	6	-	-	-	-	-	-	-	-	-	-	-	7	-	3
	10	-	-	-	-	-	-	-	-	4	3	5		22	42
	15	-	-	-	-	-	-	-	4	3	3	5		31*	59
	20	-	-	-	-	-	-	3	3	3	4	10		42*	78
	25	-	-	-	-	-	-	4	3	4	8	11		57*	100
	30	-	-	-	-	-	3	3	3	6	12	13		67**	125
	35	-	-	-	-	-	4	3	3	10	13	15		74**	140
54	5	-	-	-	-	-	-	-	-	-	-	-	7	-	3
	10	-	-	-	-	-	-	-	4	2	3	5		25	47
	15	-	-	-	-	-	-	3	2	3	4	7		33*	65
	20	-	-	-	-	-	3	2	3	3	5	11		49*	89
	25	-	-	-	-	-	4	2	3	4	11	12		61**	115
	30	-	-	-	-	3	2	3	3	9	13	14		72**	137
57	5	-	-	-	-	-	-	-	-	-	4	4	7	-	9
	10	-	-	-	-	-	-	-	4	2	3	5		25	47
	15	-	-	-	-	-	-	4	2	3	4	7		35*	68
	20	-	-	-	-	-	3	3	3	3	6	11		52*	94
	25	-	-	-	-	3	2	3	3	6	12	13		66**	126
	30	-	-	-	-	4	3	3	4	11	14	16		76**	149
60	5	-	-	-	-	-	-	-	-	-	4	4	7	-	9
	10	-	-	-	-	-	-	-	4	3	3	5		27	50
	15	-	-	-	-	-	3	2	3	3	3	9		39*	75
	20	-	-	-	-	3	2	2	3	4	8	11		58*	104
	25	-	-	-	-	4	3	3	3	8	13	14		71**	137
63	5	-	-	-	-	-	-	-	-	-	4	4	7	-	9
	10	-	-	-	-	-	-	4	2	2	4	5		30	55
	15	-	-	-	-	-	4	2	3	3	4	10		43*	82
	20	-	-	-	-	4	2	3	3	3	10	12		60**	115
	25	-	-	-	4	2	2	4	4	9	14	15		75**	147

1. Stop times include travel time from the previous stop except when a gas switch occurs.
2. Time from leaving the 9 msw stop to reaching the 12 msw chamber stop must not exceed 7 min
3. Asterisk (*) indicates number of 5 min air breaks required.

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TABLE B2. CF TABLE 14 (METRES): CUMA REPETITIVE DIVE TABLE FOR SURFACE INTERVALS FROM 3 TO 6 HOURS (VERSION 2) (cont'd)

Depth (msw)	Bottom Time (min)	Stop Times (min) at Different Depths (msw)[1]													Total Dec Time (min)
		In-Water Stops											Surf. Int. (min)[2]	RCC[3]	
		HeO_2										O_2		O_2	
		39	36	33	30	27	24	21	18	15	12	9		12	
66	5	-	-	-	-	-	-	-	-	-	4	6	7	-	11
	10	-	-	-	-	-	-	4	2	3	3	5		30*	60
	15	-	-	-	-	4	2	2	3	3	6	10		50*	93
	20	-	-	-	3	2	3	3	3	6	11	13		66**	128
	25	-	-	3	2	2	3	3	6	11	15	18		76**	157
69	5	-	-	-	-	-	-	-	-	-	4	6	7	-	11
	10	-	-	-	-	-	-	5	2	3	4	6		30*	63
	15	-	-	-	-	4	2	3	3	3	7	11		54*	100
	20	-	-	3	2	2	2	3	3	8	12	14		70**	137
	25	-	-	4	2	3	3	2	9	11	17	22		76**	167
72	10	-	-	-	-	-	4	2	3	3	3	7	7	34*	69
	15	-	-	-	4	2	2	2	3	3	9	11		59*	108
	20	-	-	4	2	2	3	2	4	10	13	15		73**	146
75	10	-	-	-	-	-	5	2	3	3	3	9	7	37*	75
	15	-	-	-	4	2	2	3	3	3	11	11		60**	117
	20	-	4	2	2	2	3	2	6	10	15	16		77**	157
78	10	-	-	-	-	4	2	2	3	3	3	10	7	40*	80
	15	-	-	4	2	2	2	3	2	6	11	12		63**	125
	20	4	2	2	2	2	2	4	8	12	18	23		75**	172
81	10	-	-	-	-	5	2	2	2	3	3	9		39*	78
	15	-	4	2	2	2	2	3	2	8	12	13		69**	137
	20	4	2	2	2	2	3	4	8	12	18	24		75**	174

1. Stop times include travel time from the previous stop except when a gas switch occurs.
2. Time from leaving the 9 msw stop to reaching the 12 msw chamber stop must not exceed 7 min
3. Asterisk (*) indicates number of 5 min air breaks required.

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List of symbols/abbreviations/acronyms/initialisms

ABCANZ	America, Britain, Canada, Australia, New Zealand
ATA	Atmospheres (absolute)
BG	Bubble Grade
BIBS	Built-in Breathing Systems
CF	Canadian Forces
CUMA	Canadian Underwater Mine-countermeasures Apparatus
DCI	Decompression Illness
DCIEM	Defence and Civil Institute of Environmental Medicine
DND	Department of National Defence
DRDC	Defence Research and Development Canada
DRF	Dive Research Facility
EDU	Experimental Diving Unit
FDU(A)	Fleet Diving Unit (Atlantic)
FDU(P)	Fleet Diving Unit (Pacific)
HeO_2	Helium-Oxygen
I.D.	Inside diameter
IWO_2	In-water Oxygen Decompression
KM	Kisman-Masurel
MCM	Mine Countermeasures
msw	Metres of seawater
NDHQ	National Defence Headquarters
NOD	No-decompression
O.D.	Outside diameter

$PiCO_2$	Partial pressure of inspired Carbon Dioxide
PiO_2	Partial pressure of inspired Oxygen
PO_2	Partial pressure of oxygen
RAN	Royal Australian Navy
RN	Royal Navy
RNZN	Royal New Zealand Navy
SAD	Safe Ascent Depth
SI	Surface interval
slm	Standard litres/min
SurD O_2	Surface Decompression with Oxygen
TWA	Time-weighted average
USNEDU	US Navy Experimental Diving Unit

DOCUMENT CONTROL DATA SHEET

1a. PERFORMING AGENCY DRDC Toronto	2. SECURITY CLASSIFICATION UNCLASSIFIED
1b. PUBLISHING AGENCY DRDC Toronto	

3. TITLE

(U) Validation of no-decompression dive limits and procedures for CUMA operations - final report

4. AUTHORS

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5. DATE OF PUBLICATION	6. NO. OF PAGES
June 6 , 2003	74

7. DESCRIPTIVE NOTES

Final report of development and validation of no-decompression dive tables and procedures for the Canadian Underwater Mine-Countermeasures Apparatus (CUMA)

8. SPONSORING/MONITORING/CONTRACTING/TASKING AGENCY
Sponsoring Agency:
Monitoring Agency:
Contracting Agency :
Tasking Agency:

9. ORIGINATORS DOCUMENT NO.	10. CONTRACT GRANT AND/OR PROJECT NO.	11. OTHER DOCUMENT NOS.
Technical Report TR 2003-029	16iq	

12. DOCUMENT RELEASABILITY

Defence departments in approved countries Carleton Life Support Technologies, Unimed Scientific Ltd. TTCP and NATO countries and agencies PFP

13. DOCUMENT ANNOUNCEMENT

Unlimited announcement

14. ABSTRACT

(U) The Canadian Underwater Mine-countermeasures Apparatus (CUMA) uses decompression tables developed and tested at DRDC Toronto (formerly the Defence and Civil Institute of Environmental Medicine (DCIEM)) to support diving to 81 metres of seawater (msw) on a breathing mixture of helium and oxygen. The no-decompression limits in these tables were not intended to be true no-decompression limits but were convenient times intended primarily for training and dive abort purposes for depths from 15 to 45 msw. The need for more realistic no-decompression limits and the extension of no-decompression diving to deeper depths included enhancing operational flexibility when undertaking short duration inspection dives, for dive abort emergency situations, and improving training and work-up programmes. A study of the DCIEM™ decompression algorithm supported extending the no-decompression limits for CUMA to 69 msw and reducing the decompression requirements for deeper short duration dives (72 and 75 msw).
Validation experiments were conducted between November 1999 and February 2002. Fifty-seven volunteer divers from the Canadian Forces (DRDC Toronto, Fleet Diving Unit (Atlantic), Fleet Diving Unit (Pacific)), Royal Navy, Royal Australian Navy, Royal New Zealand Navy, US Navy Experimental Diving Unit, and the Polish Navy participated in these trials. Dive subjects breathed from CUMA in 6 to 8°C water in a hyperbaric chamber. Inhale breathing gas was analysed continuously for oxygen and carbon dioxide. Doppler ultrasound was used for venous gas bubble detection for a minimum of 2 hours (h) after the first and second dives. Dives were repeated after 6 h to ensure that there would be no decompression penalties associated with the second dives (Nishi et. al., DCIEM TR 000-063).
A total of 128 dives (505 man-dives, with 435 being used for validation purposes) were carried out. Doppler monitoring showed that the extended bottom time limits were safe and that the differences in observed bubble scores between dives separated by 6 h were not significantly different. One case of decompression illness was observed. As a result, recommendations were made to include new no-decompression limits for diving CUMA to a maximum depth of 69 msw and reduction of stop times at 72 and 75 msw.

(U) L'appareil canadien de déminage sous-marin (ACDSM) fait appel à des tables de décompression élaborées et éprouvées par RDDC Toronto (anciennement l'Institut militaire et civil de médecine environnementale [IMCDE]) pour appuyer les plongées effectuées à une profondeur de 81 mètres d'eau de mer (msw pour meters of sea water) avec un mélange respiratoire constitué d'hélium et d'oxygène. Les limites de non-décompression de ces tables ne constituent pas des limites absolues de non-décompression, mais plutôt des limites convenant aux activités de formation et à l'interruption d'urgence des plongées effectuées entre 15 et 45 msw de profondeur. Pour élaborer des limites de non-décompression plus réalistes et étendre la portée de celles-ci aux plongées à grande profondeur, il a fallu améliorer la souplesse opérationnelle lors des plongées d'inspection de courte durée, surtout pour l'interruption d'urgence des plongées, et améliorer également les programmes de formation et d'entraînement. L'étude de l'algorithme de décompression de l'IMED™ proposait d'étendre les limites de non-décompression de l'ACDSM aux plongées effectuées à 69 mètres de profondeur et de réduire les exigences en matière de décompression pour les plongées de courte durée effectuées à des profondeurs variant entre 72 et 75 msw.
Des expériences de validation ont été réalisées entre novembre 1999 et février 2002. Cinquante-sept plongeurs volontaires des Forces canadiennes (RDDC Toronto, unité de plongée de la flotte atlantique, unité de plongée de la flotte pacifique), de la Marine royale, de la marine australienne, de la marine néo-zélandaise, de l'unité de plongée expérimentale de la U.S. Navy et de la marine polonaise) ont pris part à ces essais. Les sujets, qui prenaient place dans un caisson hyperbare contenant de l'eau dont la température oscillait entre 6 et 8 °C, respiraient au moyen de l'ACDSM. Le mélange respiratoire était sous constante surveillance afin d'en analyser la teneur en oxygène et en gaz carbonique. Un appareil Doppler a été utilisé pour détecter la présence de bulles d'azote dans le sang pendant les deux heures qui ont suivi la fin de la première et de la deuxième plongée. Les sujets ont plongé à nouveau six heures plus tard afin de s'assurer qu'il n'était pas nécessaire d'accroître le temps de décompression lors de la deuxième plongée (Nishi et. al., IMED TR 000-063).
Au total, 128 plongées ont été effectuées (505 plongées-personne, dont 435 ont servi aux fins de validation). La surveillance au moyen de l'appareil Doppler a permis de constater que les temps de plongée limites étaient sécuritaires et que la quantité de bulles d'azote formées dans l'organisme lors des deux plongées effectuées à six heures d'intervalle était sensiblement la même. Un plongeur a souffert du

mal de décompression. Suite à cet incident, il a été recommandé d'appliquer de nouvelles limites de non-décompression pour les plongées effectuée avec l'ACDSM à une profondeur de 69 msw et de réduire les temps d'arrêt à 72 et 75 msw de profondeur.

15. KEYWORDS, DESCRIPTORS or IDENTIFIERS

(U) Diving; Decompression tables; No-decompression; Doppler bubble detection; Mine countermeasures; Breathing apparatus; Helium-oxygen